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SERDP Ecosystem Management Project (SEMP)

2004 Technical Report

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SERDP Ecosystem Management Project (SEMP):

2004 Technical Report

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ABSTRACT: The SERDP Ecosystem Management Project (SEMP) was initiated in 1998 by the Strategic Environmental Research and Development Program (SERDP), after a 1997 workshop on Department of Defense (DoD) ecosystem management challenges. After the workshop, SERDP allocated initial funding to a new project, titled the SERDP Ecosystem Management Project, designated as CS-1114.

This report provides a comprehensive record of the progress and issues related to SEMP up to and during calendar year 2004. Chapter 2 provides the status and findings of the monitoring effort, while Chapter 3 describes efforts related to managing SEMP data, documents, and overall knowledge management. Chapters 4 through 7 summarize the status of the various projects and progress during FY04. This document also presents information on the SEMP integration task, site comparison indices, and the host site coordinator's report.

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Conversion Factors

Non-SI* units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
degrees Fahrenheit	$(5/9) \times (^\circ\text{F} - 32)$	degrees Celsius
degrees Fahrenheit	$(5/9) \times (^\circ\text{F} - 32) + 273.15$	kelvins
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
horsepower (550 ft-lb force per second)	745.6999	watts
inches	0.0254	meters
kips per square foot	47.88026	kilopascals
kips per square inch	6.894757	megapascals
miles (U.S. statute)	1.609347	kilometers
pounds (force)	4.448222	newtons
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square meters
square miles	2,589,998	square meters
tons (force)	8,896.443	newtons
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

* *Système International d'Unités* ("International System of Measurement"), commonly known as the "metric system."

Preface

This study was conducted for the Strategic Environmental Research and Development Program (SERDP) Office under SERDP Work Unit CS-1114, “SERDP Ecosystem Management Program (SEMP).” The technical monitor at the time of the activities included in this report was Dr. Robert W. Holst, Program Manager. The Executive Director of SERDP is Mr. Bradley P. Smith.

The work was performed under the direction of the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). Alan B. Anderson is Chief, CEERD-CN-N, and Dr. John T. Bandy is Chief, CEERD-CN. The associated Technical Director is Dr. William D. Severinghaus, CEERD-CV-T. Dr. Ilker Adiguzel is Director of CERL.

CERL is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Commander and Executive Director of ERDC is COL James R. Rowan, and the Director of ERDC is Dr. James R. Houston.

1 Introduction

Background

Mr. William D. Goran, ERDC/CERL

The SERDP Ecosystem Management Project (SEMP) was initiated in 1998 by the Strategic Environmental Research and Development Program (SERDP), after a 1997 workshop on Department of Defense (DoD) ecosystem management challenges. This workshop was held because the Department of Defense, and each of the services had issued guidance to military installations to employ scientifically sound and adaptive ecosystem management approaches to manage military owned/used lands, and the services had identified research needs related to this guidance.

Below is an excerpt from an 8 August 1994 memorandum from Sherri Wasserman Goodman, who was then Deputy Undersecretary of Defense for Environmental Security, on ecosystem management:

I want to ensure that ecosystem management becomes the basis for future management of DoD lands and waters. Ecosystem management is not only a smart way of doing business, it will blend multiple-use needs and provide a consistent framework to managing DoD installations, ensuring the integrity of the system remains intact. Ecosystem management of natural resources draws on a collaboratively developed vision of desired future ecosystem conditions that integrates ecological, economic, and social factors. It is a goal-driven approach to restoring and sustaining healthy ecosystems and their functions and values using the best science available. The goal is to maintain and improve the sustainability and native biological diversity of terrestrial and aquatic, including marine, ecosystems while supporting human needs, including the DoD mission.

The purpose of the 1997 SERDP workshop was to focus, clarify, and prioritize Defense installation ecosystem management research needs related to this guidance. During this workshop, the key themes that emerged included: (1) understanding the status and trend of ecosystems and the role of military use related to status and trends, in relation to the desired conditions identified in the “goal driven approach to restoring and sustaining healthy ecosystems” targeted in the Goodman memo-

random, (2) understanding the management “thresholds” for ecosystem conditions, beyond which closer observation and/or mitigating action may be required, (3) understanding the biogeochemical cycles (functions) in the ecosystem, and how military land use and resource management practices impact these cycles, and (4) understanding all of these phenomena at the multiple spatial and temporal scales, from ecoregions to micro-organisms and across days, years, and decades, impacted by military use and management of lands and waterways.

After the workshop, SERDP allocated initial funding to a new project, titled the SERDP Ecosystem Management Project (SEMP), designated as CS 1114, and requested that the Corps of Engineers research laboratories manage this project and establish a planning team. Fort Benning, GA, volunteered to host the research program and the planning team developed an initial research statement of need (SON) for work on the issue of indicators of ecosystem status. Proposals for this statement of need were reviewed in spring 1999, and three research teams (University of Florida, Construction Engineering Research Lab/Prescott College, and Oak Ridge National Lab) were selected to begin multiyear research initiatives against this theme. Chapters 4 through 7 summarize these projects’ status and progress during Fiscal Year 2004 (FY04). Project 1114D (Garten), was completed in 2003 and does not have a chapter in this report.

In addition, a monitoring program was initiated, in 1999, to establish a long-term set of meteorological, aquatic, and terrestrial conditions for Fort Benning and the surrounding ecoregion. Chapter 2 provides the status and findings of this monitoring effort during FY04.

Since SEMP field work began in 1999, many new research efforts have been added. Some of these efforts are formally included within SEMP (such as the two threshold projects started in FY00) and many others are leveraging SEMP to explore additional issues at Fort Benning or at other locations along the Sandhills Fall-Line area or in the Southeastern Coastal Plain. Fort Benning straddles both these ecoregions. Figure 1-1 shows the numerous military installations in this region of the southeastern United States, against green areas that represent ecologically valuable lands in the region. These ecologically valuable lands, which often include military installations, were identified through an analysis conducted by the University of Florida, the Southeastern Region of the Environmental Protection Agency, and other agencies that work together in the Southeastern Natural Resources Leader’s Group.

Some of these additional projects are sponsored by SERDP, while others are sponsored by Army research programs, leveraged by local universities, or sponsored directly by Fort Benning or other Federal facilities in the region.

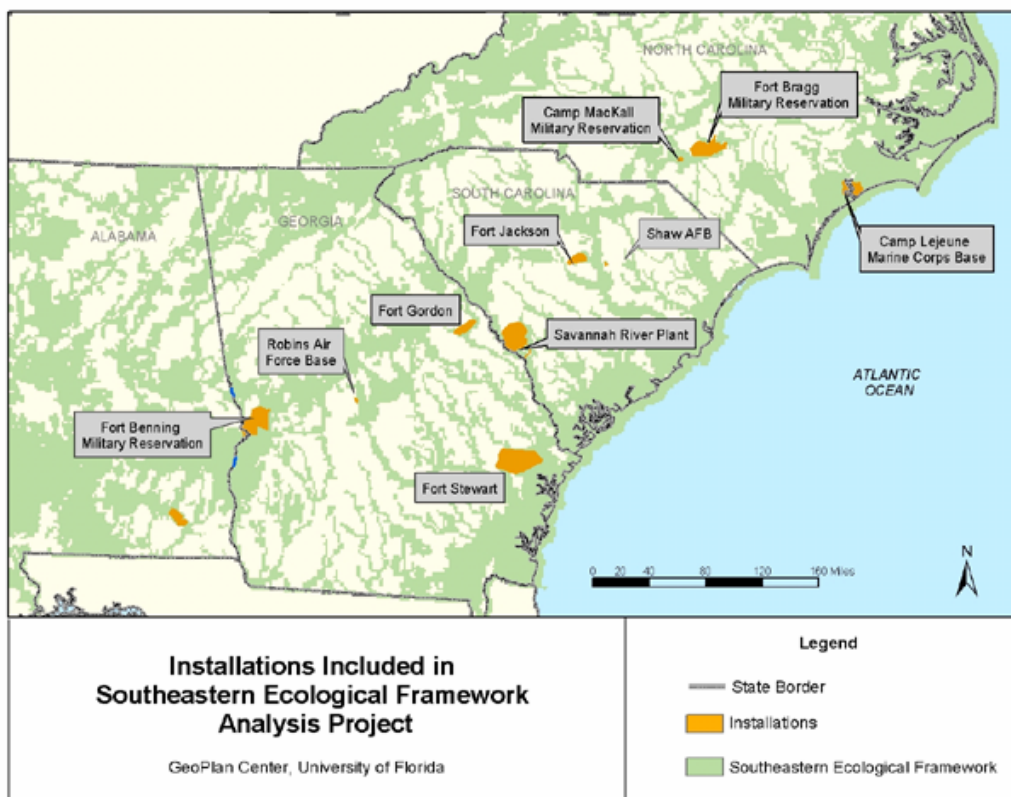


Figure 1-1. Military installations in the Southeast (including Fort Benning). Green areas are part of the “Ecological Framework” developed by the University of Florida and the Southeastern Region IV of the Environmental Protection Agency.

Objectives (pre-2005 changes)

The overall objectives established for SEMP are to:

- Address DoD requirements and opportunities in ecosystem management research (1997 SERDP Ecosystem Science Workshop) as identified in the 1997 workshop on ecosystem management research challenges for the Department of Defense.
- Establish a long-term research site (or sites) on DoD lands for DoD-relevant ecosystems research.
- Conduct additional ecosystem research and monitoring activities relevant to DoD requirements and emerging opportunities.
- Develop ecosystem management tools and practices for and transition to DoD land managers.

SEMP is organized to pursue each of these objectives.

Objectives of 2004 Report

The objective of this report is to provide a comprehensive record of the progress and issues related to SEMP up to and during calendar year 2004. Previous reports covered fiscal year progress for previous years, including the following:

- Unpublished report: Plans and Progress of the Strategic Environmental Research and Development Program (SERDP) Ecosystem Management Project (SEMP), April 2000.
- ERDC SR-01-3: Strategic Environmental Research and Development Program (SERDP) Ecosystem Management Project (SEMP) FY00 Annual Report, September 2001.
- ERDC SR-02-2: Strategic Environmental Research and Development Program (SERDP) Ecosystem Management Project (SEMP) FY01 Annual Report, March 2002.
- Unpublished report: Strategic Environmental Research and Development Program (SERDP) Ecosystem Management Research Project (SEMP) FY02 Annual Report, March 2003.
- SERDP Ecosystem Management Project (SEMP) 2003 Technical Report, ERDC/CERL SR-04-3, March 2004.
- SERDP Ecosystem Management Project (SEMP) 2003 Administrative Report, ERDC/CERL SR-04-4, March 2004.

The current report includes all phases and projects directly related to SEMP, including the monitoring efforts, the five research projects that are formally managed as part of SEMP (identified as CS1114A through CS1114E in Chapters 4 through 7). A companion document (*SERDP Ecosystem Management Project (SEMP) 2004 Administrative Report, ERDC SR-06-1*) discusses the various SEMP management, coordination, and technical oversight activities.

The numerous projects that leverage SEMP each develop their own reports, and there is no attempt, within this report, to provide a comprehensive account of their progress.

Approach

The overall approach for SEMP is pictured in Figure 1-2. This figure, presented to the SERDP Scientific Advisory Board in March 2003, depicts the “flow” of activities for SEMP, moving from the identification of research themes through the competitive solicitation of proposals against each of these themes; the progression of the research; the publication, testing, and validation of outcomes; and transition to the host installations and to other sites beyond the host. The project as a whole is man-

aged by the Engineer Research Development Center (ERDC) of the U.S. Army Corps of Engineers. ERDC provides a Project Manager who is assisted by a Research Coordinator, a Monitoring Team Coordinator, a Repository Coordinator, a Host Site Coordinator, a Technology Transfer Coordinator, and a Reporting Coordinator.

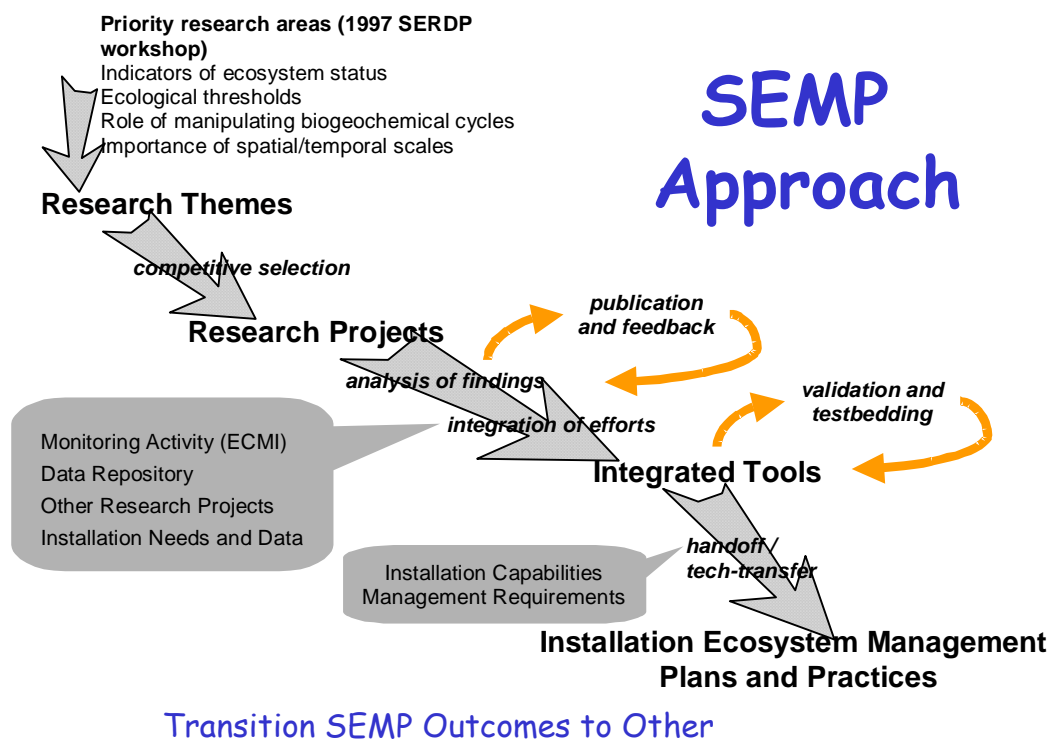


Figure 1-2. The SEMP Approach.

Because SEMP is a SERDP project, proposal solicitation, evaluation, and selection practices follow the SERDP approach (posted on the SERDP website at <http://www.serdp.org>). Once a solicitation is posted on the SERDP website, teams from government, industry, and/or academia draft proposals to address the solicitation. These proposals are reviewed for relevance, and those that are found sufficiently relevant to the solicitation are sent out for a peer review process.

For SEMP solicitations, proposals that emerge successfully (recommended for funding) from the peer review are then reviewed by the SEMP Technical Advisory Committee (TAC) and by the host installation(s). This SEMP TAC group, which first started functioning in 1999, was established to provide oversight, guidance, and coordination for the SEMP projects. Finally, any proposal(s) that is recommended for funding by the SEMP TAC is forwarded to the SERDP Executive Director, to concur or non-concur with the recommendation. Before a new effort is funded, it is also

briefed to the SERDP Scientific Advisory Board (SAB), which is a congressionally mandated scientific oversight board for all of SERDP.

After successful review and authorization to proceed, research investigators begin their work, as per their proposed plans. Besides pursuing their research objectives, SEMP investigators collaborate across teams, and there are numerous means to facilitate this collaboration. Annual Research Coordination meetings have been held since 1999. All data from research and monitoring is placed in a central repository (described in Chapter 3). Teams brief their progress once or twice each year to the SEMP TAC and are encouraged to make presentations at the annual SERDP Symposium, and often at other scientific forums, such as the Ecological Society of America, the American Society of Agronomy, and the North American Wildlife Society.

In 2002, the TAC recommended that a research integration effort be designed. This effort was started in 2003 and continued through 2004. Progress for this integration effort is reported in Chapter 8, SEMP Integration Project (SIP). This project is designed to identify, screen, and verify proposed indicators of ecological status emerging from across the research teams related to a common installation landscape framework.

The SEMP Integration Project is developing candidate indicators of ecological status, based on long-term management objectives and military use activities conducted at different locations at Fort Benning. These indicators are being screened and tested, through a series of steps, before they are transitioned to installation use. This is one of the two complementary approaches to help transition promising outcomes (indicators, thresholds, and other potential outcomes) from SEMP (and related efforts). The other is through the Sandhills Fall-Line initiative, which was presented to the SEMP TAC in 2001, then approved in 2002 for inclusion in the 2003-2006 SEMP plans.

In October 2003, the SERDP Scientific Advisory Board requested that SEMP be “restructured” to address several concerns. In response to this request, the SERDP Program Office asked RAND Corporation to conduct a comprehensive assessment of SEMP and make recommendations for restructuring SEMP. This assessment was conducted from April through August 2004, and preliminary results were reported to the SERDP SAB in September 2004. Later in the same month, the RAND preliminary results were also reported to the SEMP TAC. A final report was provided to the SERDP Program Office in November 2005.

Overall, the RAND assessment found several problems with SEMP, but the RAND team thought that SEMP should be continued with efforts to address these problems and make the project more relevant to Fort Benning ecosystem management

challenges. The report recommended a process, including a workshop, to consider the assessment and develop a restructuring plan. This process was initiated, with SEMP TAC involvement, in December 2004. A workshop was conducted at Fort Benning in early February 2005.

Mode of Technology Transfer

This report will be made accessible through the World Wide Web (WWW) at URL: <http://www.cecer.army.mil>

As mentioned, the methodology and plans for SEMP technology transfer are provided in Chapter 12, Technology Transfer.

SEMP also aggressively uses many different means to ensure that information about SEMP and outcomes from SEMP are available to all potentially interested parties. The SEMP website is at <http://www.cecer.army.mil/KD/SEMP>. This site is referenced from the SERDP site and from the Defense Environmental Network for Information Exchange (DENIX) <http://www.denix.osd.mil>.

Besides this website, SEMP has a periodic newsletter (*SEMP Postings*) and is now developing a communication plan. The development of this plan is primarily a 2005 activity, but it was strongly suggested in the 2004 RAND assessment of SEMP, along with numerous other adjustments. In addition, there have been dozens of presentations about the plans for and progress of SEMP to numerous military and Federal forums, and also to scientific meetings.

The Fall-Line Sandhills initiative, which is a component of SEMP, is intended to facilitate partnering opportunities related to ecosystem management research and management at multiple locations along this Sandhills Fall-Line ecoregion. A multi-organization team, led by the SEMP Project Manager, planned a second “Partners Along the Fall-Line Workshop” at Savannah River Site Conference Center. This Workshop was held 8 – 10 March 2005 and was attended by more than 50 individuals from numerous state, Federal, and non-government organizations. This initiative represents one of the key technology transfer components of SEMP. The results of this workshop will be reported in the SEMP 2005 Technical Report.

Finally, all promising outcomes from the research projects and also from the monitoring effort, as well as new data, analysis tools, identification keys, and other relevant capabilities emerging from SEMP, are planned for infusion to installation operations, at the host location(s), and at all other relevant and interested sites in the southeastern United States and beyond. All such transitions are, of course, guided

and constrained by the relevance of these research and monitoring outcomes to military installation ecosystem management goals and objectives.

One of the primary modes of technology transfer is publications and presentations. A complete listing of these presentations and various types of publications is provided in Appendix A.

2 Long-Term Monitoring

2004 Annual Report

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Introduction

Within the SEMP, the long-term ecosystem characterization and monitoring initiative was established to design, develop, and demonstrate an ecosystem characterization and monitoring concept appropriate for military installations. The products must support multiple SEMP objectives and be beneficial to installation land managers. The baseline monitoring concepts are intended to have broad applicability and may serve as a model for other installations.

Project Duration and Funding

FY99 (\$K)	FY00 (\$K)	FY01 (\$K)	FY02 (\$K)	FY03 (\$K)	FY04 (\$K)	FY05 (\$K)
530.0	655.0	300.0	325.0	325.0	400.0	325.0

Objective

The objective of the monitoring initiative is to develop a framework to characterize the long-term spatial and temporal dynamics of key ecosystem properties and processes in a way that is jointly beneficial to ecosystem research activities and military land management operations. The monitoring is expected to produce a multi-purpose, integrated, baseline ecological information base. This information base will:

1. support SEMP ecological research related to sustainable management of DOD lands,
2. contribute baseline level biotic and abiotic data to the integrated monitoring plan of the host site,
3. establish a long-term ecological data set at the host site that will, over time, allow the assessment of relationships between land use, management and ecosystem sustainability, and
4. be compatible with monitoring data sets collected by other agencies in the region.

Approach

The approach has been to complete the design and implementation phase (Phase I, 1999-2001) as described in “*Long-Term Monitoring Program, Fort Benning, GA.*”^{*} Some adjustments have been made to the original design; in particular to the surface water component because of the extended drought being experienced in the Fort Benning region. The long-term monitoring is currently in the modification phase (Phase II, 2002-2005) and the research team has begun to develop technology transition plans for several components. The first component to be transitioned will be the meteorological component; land cover monitoring and surface and ground water components will follow. The first step in the transition plan has been to develop a “lessons learned” knowledge base to help guide the transition process.

Lessons Learned During FY04

Throughout the monitoring period from August 1999 to the present, there have been several lessons learned concerning hardware selection, installation, and implementation as well as equipment performance. All of the abiotic data acquisition stations are standalone, self-powered systems. This presents the challenge to supply and maintain sufficient power to operate the datalogger and its sensor suite as well as power for cell phone communication. Overall, the meteorological stations have performed well. Problems experienced are described as follows.

Meteorological Monitoring

A lightning strike at the Natural Resources site damaged the datalogger, wind monitor, and air temperature/relative humidity sensor. The intermittent symptoms exhibited in the data initially indicated damage limited only to the sensors. These were changed and all problems appeared to be resolved; but the problem reappeared. A datalogger swap solved the problem and the damaged datalogger was returned to the manufacturer for evaluation and repair, where it was determined that the lightning damage prevented total repair with confidence.

Also at the Natural Resources station the evaporation sensor required replacement due to excessive wear in the water level potentiometer. This prevented smooth float

^{*} Kress, M. Rose. 2001. *Long-term Monitoring Program, Fort Benning, GA: Ecosystem Characterization and Monitoring Initiative, Version 2.1.* ERDC/EL TR-01-15. U.S. Army Engineer Research and Development Center.

travel and produced erratic data. The damage to the potentiometer was evaluated as being caused by normal wear. This sensor was replaced and the faulty component will be repaired by potentiometer replacement.

At the Ranger station, ME03, a circuit failure in the cell phone created a short that allowed a power drain on the system's main power supply. This would deplete the battery to the point that the datalogger would not run its scheduled data acquisition routine, instead going into a sleep mode. During daylight hours the station's solar panel would recharge the battery to a level that would permit datalogger operation for a short period of wake time, then collection would stop in the night hours. Replacement of the cell phone remedied the problem. Neither the datalogger nor any sensors at this station were permanently damaged from this problem.

The Alabama meteorological station, ME09, also experienced power supply problems from a different source. Somewhere in the system was a constant power drain that consumed power faster than the solar panel could provide. The usual methods of on-site problem shooting were employed to solve the problem and at times it appeared were successful. Diagnosis of the problem was further complicated due to the fact that the problem would not occur until several days after the battery had been exchanged. However, recurrence of the problem persisted. A detailed system check finally discovered that the storage module, used as a means of data storage redundancy, had failed and was the source of the power drain. In more than 10 years of experience and use of nearly 100 of this type of modules, this is the only instance in which this problem has occurred. The module was replaced and the station continues to operate properly.



Figure 2-1. A typical meteorological data acquisition station.



Figure 2-2. A typical surface water monitoring station.

The environment at the McKenna MOUT site, ME04, is different than the other sites. The immediate area surrounding this station is used for troop training and maneuvers. This includes occasionally airlifting personnel into the area using helicopters that naturally create periodic clouds of dust and grit. The high incidence of these airborne particles accelerates wear on the wind monitor at this station, requiring more frequent sensor monitoring and exchange.

The sole problem at the Cactus site, ME05, consisted of the mounting bracket for the solar panel becoming loose. This allowed the panel to reorient itself to a less-than-optimum position for recharging the power supply. Sufficient power was maintained with no loss of data acquisition and the panel secured.

The meteorological stations are necessarily located in open areas. As such, the station at Hastings, ME06, is located near the perimeter of a tank training/firing range. In one instance the wind monitor and cables sustained physical damage from the heat of either a controlled burn initiated by the forestry section of Natural Resources or a fire started from tracer rounds. Damage was cosmetic and did not compromise the data. As a note, forestry section personnel of the Natural Resources office are aware of all of the research sites with deployed equipment and make every effort to avoid these areas. In fact, the forestry section personnel retrieve and reference the data from these sites to assist their decisions concerning controlled forestry burn schedules.

Surface Water Monitoring

Automated unattended data acquisition of water quality parameters has proven to be difficult. The initial proposal included the installation of an unattended multiprobe unit that would transfer its data to the datalogger, which would store the data until retrieved via cell phone. The multiprobe would contain the desired sensors for DO, pH, conductivity, turbidity, and temperature. The data for level, flow, and a second temperature probe are collected from discrete sensors. A problem that became obvious rather soon was one of individual sensor degradation due to bacterial buildup and fouling from water contaminants. A series of streamside field site visits to perform sensor cleaning and calibration checks was performed to try to establish a maintenance schedule that would provide data within the sensor specifications. Logistically this was cumbersome at best, requiring personnel to carry in necessary cleaning supplies and hardware as well as calibration standards, measuring devices, and replacement sensors. The trial included four different sites and over a period of time, it became apparent that each site exhibited a different rate of degradation, necessitating different schedules. Also, this routine would be required after each significant precipitation event as the stream level elevated and receded. From these labor-intensive efforts it was determined that the number of site visits necessary to maintain sensor integrity would be cost prohibitive. It has been decided that bi-weekly visits would provide needed data for water quality information. This water quality evaluation includes performing in-lab multiprobe sensor calibration prior to site visit and recording parameter findings from each site.

Stream information regarding level, flow, and temperature will continue to be collected with the automated data acquisition system. The data acquisition record at all sites improved after the decision was made to exclude the Hydrolab®* multiprobe from the datalogger. The inherent requirements of the multiprobe including power and data formats complicated its implementation.

Adding to the surface water data acquisition problem for the first 2.5 years (summer 1999 through summer 2001), was the fact that the southeastern United States was experiencing a long-term drought that was reflected in unusually low water conditions. In some instances at least one of the creeks experienced a no flow/low flow state resulting in stagnant pools and extreme water quality conditions.

* Hydrolab is now HACH Environmental, P.O. Box 389, Loveland, CO 80539.

Other problems were experienced at Upatoi Creek, Randall Creek, and Oswichee Creek. The equipment at Randall Creek, WS21, sustained the only act of vandalism associated with ERDC property. During the data collection period cables for the level, flow, and temperature sensors were cut and destroyed and the station equipment ransacked. Nothing was missing but replacement sensors were not available and it was decided to remove all hardware until replacement sensors could be acquired.

The station at Oswichee Creek, WS20, was destroyed by an unusually high water level; locals claimed a 100-year event, which occurred after several days of heavy rains. The creek over banked and submerged the equipment. Stream levels that usually run 1.5 to 2 meters went to an estimated 6 meters. There were two sets of data acquisition at this site and all equipment and most of the sensors were damaged beyond repair.

The stations at Randall Creek and Oswichee Creek have been repaired and are proposed to be re-established in 2005 as part of the effort to adapt the surface water monitoring protocol to better meet emerging installation needs to monitor Total Maximum Daily Loads (TMDL) for certain water quality parameters.

Problems at the Upatoi station, WS14, were comparatively minor. When the station was installed, sensor cables were left lying on the ground between the tripod and the sensor housing. At some point, some type of animal chewed through the temperature sensor cable coating and eventually the conductor. Replacement of the sensor and stringing the cables from the tripod to an elevated pipe solved the problem.

The system installed at Little Pine Knot, WS22, required replacement early in the project due to lowland flooding and improper equipment installation. Since replacement, the major problem consists of power supply. Being located in a lowland/valley area surrounded with non-deciduous trees decreases solar potential. Monthly site monitoring with battery replacement is required to assure adequate power.

Power supply problems were experienced at the Bonham Creek, WS11, site as well. Surrounding vegetation and terrain are similar to Little Pine Knot and similarly, monthly monitoring and exchange of the battery helps the data acquisition effort.

Sally Branch data acquisition has continued with minimal problems. It too, suffers from power supply problems but to a lesser degree due to a more open area with better solar access.

Ground Water Monitoring

Four groundwater wells were developed across the installation to monitor the ground water levels. These are located near existing surface water monitoring stations at Randall Creek, Sally Branch, Little Pine Knot, and Oswichee Creek. A fifth well was attempted at Bonham but was abandoned after drilling a 60-foot dry hole. Data from each well are acquired with a permanently placed pressure transducer, mini-troll, which monitors the depth of the water column. This distance is referenced to the top of the well casing. At project outset the initial procedure for data retrieval from the mini-trolls was to retrieve the mini-troll using the wire rope tether, unscrew the backshell, attach a data interface cable to the mini-troll and a laptop, and download the data. This process eventually proved to be problematic due to the connector interface from the data cable to the mini-troll. The physical structure of the connector's contacts is fragile by design and misalignment or damage to the contacts was likely. A description of this connector would be of a flexible elastomer board, 5/8" x 1/2" x 1/8", overlaid on three sides with approximately 100 thin-film gold traces. When attaching the backshell or the interface cable, one edge of this board and its thin-film contacts would necessarily physically contact the mating connector, sometimes damaging the thin-film contacts. When the connector board was damaged, a replacement board would be tediously installed and the backshell or interface cable attached. As battery life in these sensors runs 1 to 2 years, the only reason to breach the connector/backshell/interface is data retrieval and sensor health status. To remedy this problem an interface cable was acquired to act as a tether/interface so the mini-troll can remain in place and the data retrieved without problems. To further reduce the chance of connector damage, an in-line battery pack that will increase battery life to 7 years is being anticipated. Also, the construction of the connector board has been improved to incorporate a more secure contact bonding process, which should help to decrease problems.

Data Retrieval

The procedure for automated data retrieval via cell phone communication requires a dedicated Windows-based PC with an analog modem and phone line. Due to military installation network security issues, the PC used to download data via modem is not allowed to be connected to the installation network. Because the system is continuously running, the system should be protected from outside phone line interference, lightening, and power fluctuations with the necessary uninterrupted power source (UPS). Once the PC loses power, the retrieval application closes and must be manually restarted. Once this is done, the application will automatically acquire data that had not been retrieved and update the data files.

Due to the continuous operation of the retrieval system, the health of the system's hardware should be periodically reviewed for potential problems. Some observations would be the power supply and its cooling fan, the processor's cooling fan, the system's hard drive, and any interface cables. Periodic system integrity checks can be performed on the modem as well.

The datalogger's internal memory buffer will retain some data but it is advisable to perform periodic data backup of the retrieval system's hard drive. This can be written to a CD-RW on a routine basis of 3 to 4 weeks with no loss of data.

If cell phone communication is used for data transmission from the field station, it is advisable prior to installation and equipment purchase, to ascertain that appropriate cell phone coverage is available for the sites selected. One must also understand that there are two types of cell phone transmission: analog and digital. Analog is preferable for this remote service, as it allows the use of 3-watt transmitters, which increases the available range. However, analog cell phone service is slowly being phased out to eventually be replaced with digital. Typical digital service is limited to 300 milliwatts but there are power amplifiers available that will boost the signal. This approach could be used but it would increase the power demand on the station power supply. Other retrieval methods are available and should be evaluated as well. This is a major unresolved problem area, and will remain so until new technologies are available.

Data Quality Check

As mentioned in the Data Retrieval section, data is retrieved daily via cell-phone from the 10 meteorological stations and Sally Branch water station to a desktop computer. When possible, data are reviewed on a near-daily basis to monitor any problems. Each parameter of each data file is observed in a graphical form that would highlight problems and any erroneous data. Data outside of the sensor limits are automatically tagged with an error code, which can be interpreted as a null value in data analysis. Further examination of specific parameters assures the quality of the data prior to inclusion in the data repository. This initial quality check is primarily utilized as a tool for maintenance and troubleshooting the data acquisition system's condition, but the process ultimately provides the opportunities for final error checking and annotation.

Final error checking is performed similarly to the daily process but uses the entire month's data file. Once the final data check has been performed and errors or outliers annotated, the data file is tagged with the appropriate file name and transferred for inclusion to the data repository.

Transition Recommendations for Meteorology

The present 10-station network cannot be sustained by research needs, and cannot be used to support installation needs. While the perpetuation of the present database is desirable, the system will have to become more useful and sustainable to ensure long-term viability. To address these issues, a series of decisions will have to be made.

The ultimate goal would be a system similar to the Georgia Automated Environmental Monitoring Network, where data is downloaded frequently (every 15 minutes) to a server and processed into a useful interface available to all on the Internet. This system would maintain archived data sets compatible to those presently collected, and satisfy the needs of potential users on the installation and throughout the region. This system will require more power and airtime than is currently available. If such a system isn't possible, it would be desirable to upgrade some of the stations to support queries based on specific user needs as described below.

If it is a requirement to continue to build upon the existing data base, the current number and locations of weather stations cannot be substantially changed. In this case, the existing weather stations should be connected to phone service wherever possible, solving the power problem and reducing the cost of connectivity. Where hard-wire phone service is not available, electrical service can be used to amplify the digital cellular signal and fully support multiple users. At sites where neither power nor phone wired connections is possible, the solar system can be up-graded — particularly if other stations are hardwired — freeing up solar panels and batteries.

The necessity of maintaining a 10-station system should be reassessed based on the first 5 years of deployment. The weather data collected to date should be examined to determine how different the conditions are between stations. This information could be used to justify a reduction (or increase) in the number of stations. Alternate sites, with electricity and phone, may provide comparable data and therefore replace two or more existing stations.

In any case, the design goal of the monitoring initiative was to provide archival data, not direct user access. The connectivity and power requirements will have to be addressed by modifications to the hardware. A user-friendly interface that provides access to the data is required by anyone that needs to determine current meteorological conditions.

The Georgia Automated Environmental Monitoring Network (AEMN) (www.Georgiaweather.net) operates a network of more than 50 weather stations throughout Georgia. This project, executed by the University of Georgia, has devel-

oped the interface that is necessary to attract users to the Fort Benning system. AEMN has programmers and technicians in place who are familiar with the equipment and problems that the monitoring program faces. The most efficient path forward would be to relocate a subset of the monitoring stations to locations that have hardwire phone service and incorporate them into the AEMN network. This will provide the enhanced usability needed to attract new users, while maintaining an archival database of installation-wide meteorological conditions. This would lower the operating costs, attract new users, and build on the AEMN network and maintenance infrastructure. This would increase the likelihood that funds to support the long-term data collection at Fort Benning could be maintained past the FY09 SERDP commitment to the installation.

A reasonable approach would be to have the Fort Benning Land Management Branch, Directorate of Operations and Training and the AEMN establish an Internet-connected weather station at the Natural Resources Building. This station would provide all users with up-to-the-hour weather data and would serve as a prototype for subsequent system improvements.

Aquatic Monitoring

Macroinvertebrate samples and data describing environmental and physical habitat parameters were collected at 21 locations from among 18 second to sixth order streams at Fort Benning during fall 2003 (Figure 2-3). In spring 2004, similar methods were used at nine sites in five streams associated with the new Digital Multi-purpose Range Complex (DMPRC). At each 100-m site, standard Rapid Bioassessment Protocol scores^{*} were estimated to provide a general characterization of physical habitat quality. Environmental data describing pH, turbidity, conductivity, and dissolved oxygen concentration also were collected. Benthic macroinvertebrates were collected at each site to indicate biological variability among streams.

^{*} Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B. (1999). *Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates, and fish*, 2nd Ed., EPA 841-B-99-002, U.S. Environmental Protection Agency, Washington, DC.

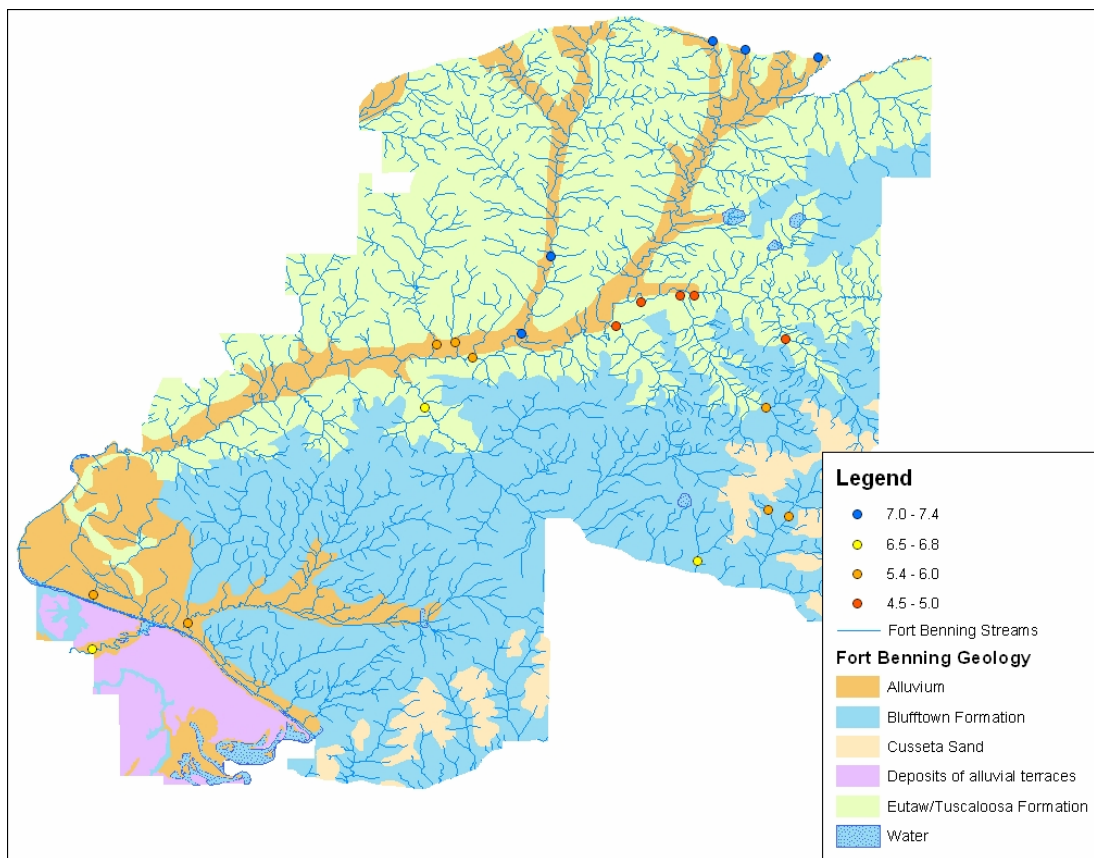


Figure 2-3. Location of stream sites sampled during fall 2003 at Fort Benning. Geologic formations and pH also are indicated by color

Fall 2003 Sampling. There are two prominent physiographic regions within the installation boundaries: (1) upland sandy hills region and (2) coastal plain region. Streams within the upland area tend to have lower turbidity, higher pH, relatively little stable substratum, and less overall habitat diversity than streams in the coastal plain area of the base. For this reason, two variables that are particularly useful to distinguish among streams are Rapid Bioassessment Protocol (RBP; indicative of physical habitat quality) and pH.

Measured pH values among the 21 sites ranged from 4.5 to 7.4 (Figure 2-4). Upland streams, including Randall Creek, Tar River, and Cox Creek, consistently have the highest pH values (7.0-7.4) of all Fort Benning streams, whereas Pine Knot, Little Pine Knot, Sally, and Bonham Creeks typically have the lowest pH values (4.5 to 5.0). Other streams such as Hollis, Oswitchee, Laundry, and Ochillee Creeks typically have acidic pH values, although these values are moderate among all streams on the base (~5.5 to 6.5). These pH values seem to be related, at least partially, to variability in geology and soil chemistry (Figure 2-3).

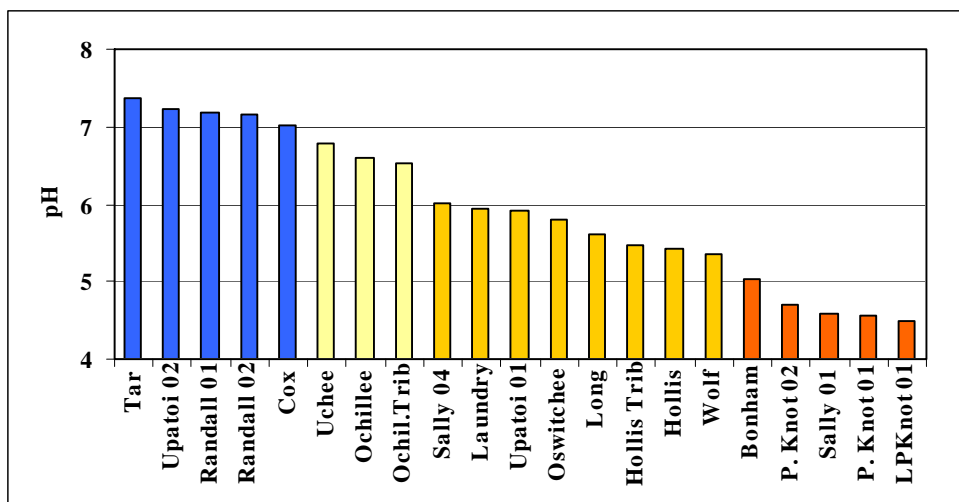


Figure 2-4. Measurements of pH at Fort Benning stream sites sampling during fall 2003.

Physical habitat quality also differs between streams in the two physiographic zones. RBP scores in upland streams were generally lower than those of coastal plain streams (Figure 2-5). One exception was Cox Creek, which had the highest score (RBP = 173) of all creeks. However, Cox differed from other upland streams by having substantial diversity in depth and substrata, the amount of stable substrata, and a limited amount of sediment deposition within its channel. The lower Ochillee Creek site also had a relatively high RBP score due to instream stable substrata and depth diversity.

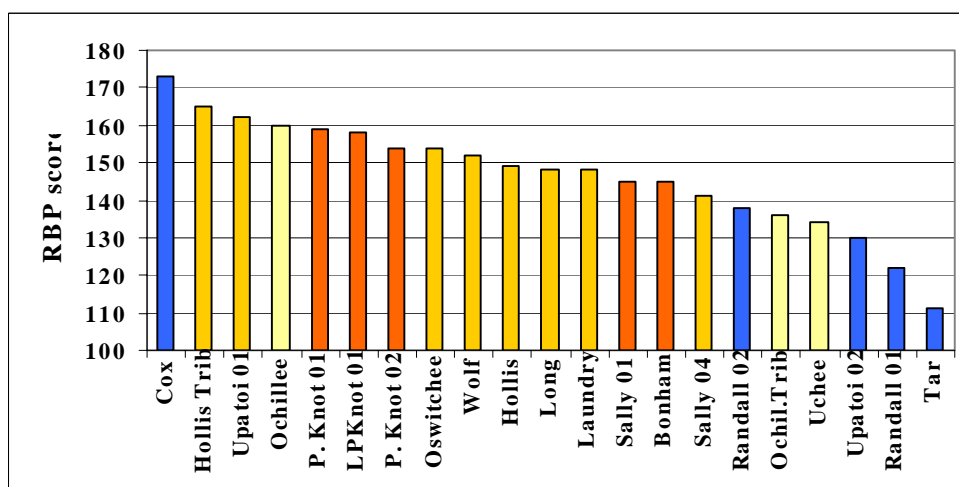


Figure 2-5. Rapid Bioassessment Protocol (RBP) scores for stream sites sampled during fall 2003. Color codes for pH are retained from Figure 2-3.

Generally, pH and physical habitat quality are negatively correlated among Fort Benning streams (Figure 2-6). However, preliminary analyses of biological data do not indicate clear trends that might explain how these factors might affect macroinvertebrate assemblages in upland and coastal plain streams. It is possible that macroinvertebrate abundance and diversity in upland streams may be limited by poor habitat quality, while pH may act as a limiting factor for macroinvertebrates in the coastal plain streams. Although experimental testing of these hypotheses is beyond the scope of this study, further analyses of these and future data will hopefully prove helpful in addressing these questions.

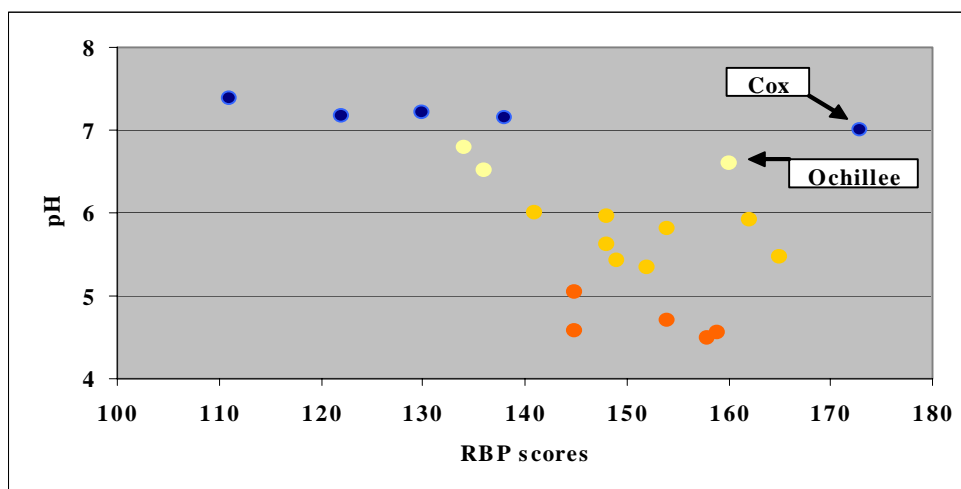


Figure 2-6. Comparison of pH and RBP among stream sites sampled during fall 2003. With the exception of Cox Creek and Ochillee Creek, these two factors are negatively correlated (i.e., streams with better physical habitat have lower pH, whereas streams with higher pH have poorer quality habitat).

Spring 2004 Sampling. Methods similar to those used during fall 2003 were used to collect data describing physical, environmental, and biological conditions at nine sites within five separate streams associated with the DMPRC at Fort Benning (Figure 2-7). The specific streams sampled included Sally Creek (three sites), Pine Knot Creek (two sites), a tributary of Pine Knot Creek, Bonham Creek (two sites), and a tributary to Bonham Creek. The purpose of this effort was to gather pre-construction data that might be useful in making a post-project evaluation of stream impacts.

All of the DMPRC sampling sites were located within a relatively small coastal plain section of the base. As expected, pH was similar among these sites (pH = 4.9 to 6.1). Instream deposition of loose sand was prevalent at the Pine Knot tributary site (RBP = 137); RBP scores were similar among the other 8 sites (150 to 159; Figure 2-8).

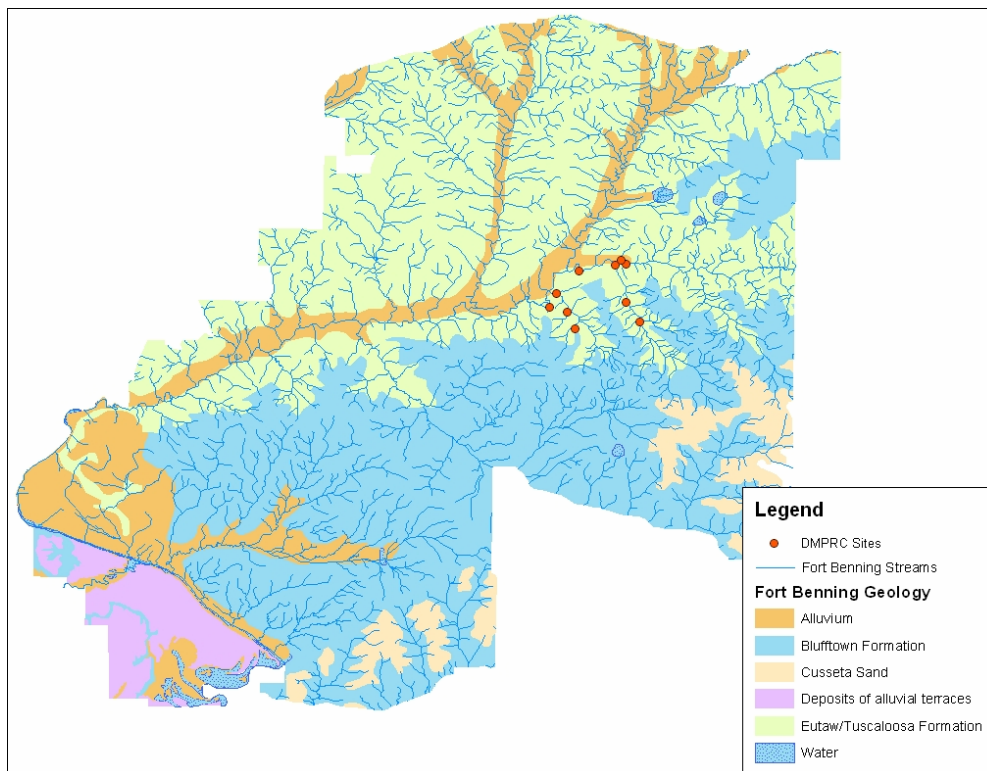


Figure 2-7. Stream sites sampled during spring 2004 prior to construction of DMPRC at Fort Benning.

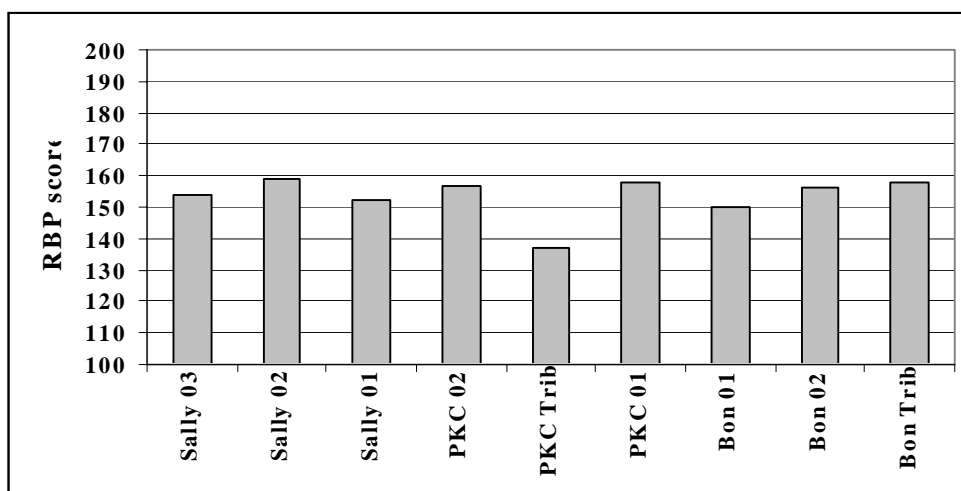


Figure 2-8. RBP scores for Fort Benning stream sites associated with the DMPRC (spring 2004).

Benthic macroinvertebrates were sampled from each substantial habitat type represented at a site; stratified samples weighted by habitat abundance were combined into a sample composite. A direct count of 250 + 10% organisms were then ran-

domly removed from the composite material and identified to genus when possible, except chironomids and oligochaetes. Two types of calculations were used to provide biological indicators of habitat conditions for each site. First, environmental tolerance values^{*} were used to calculate mean tolerance values (Index of Biotic Integrity; IBI) for organisms collected at each site. Low IBI scores indicate low tolerance to environmental perturbation, whereas high IBI scores are indicative of organisms often associated with degraded or poor habitats. Second, organisms of the taxonomic orders Ephemeroptera, Plecoptera, and Trichoptera are generally considered “intolerant” to environmental perturbation. Therefore, percent Ephemeroptera, Plecoptera, and Trichoptera (%EPT) and IBI, which are expected to be negatively correlated, were used to indicate relative differences in habitat quality among sites.

There were consistent differences in IBI and %EPT among sites of different creek systems (Figure 2-9 and Figure 2-10). The three Sally Creek sites had both the highest IBI scores and lowest %EPT estimates among all sites; these results indicate that the relative habitat quality in Sally Creek is lower than in Pine Knot Creek and Bonham Creek. IBI and %EPT estimates from within the Bonham Creek drainage indicated higher habitat quality relative to the other two creek systems. These differences in calculated IBI and %EPT among stream systems can be attributed to differences in relative abundance of early instar Chloroperlidae mayflies. Chloroperlids were much more common in samples from the Bonham Creek sites (27 to 88 individuals) than those from Pine Knot (8 to 18 individuals) and Sally Creek (0 to 4 individuals) sites. Since choroperlids are of the Order Ephemeroptera and have a very low environmental tolerance value (1), differences in their abundance among stream sites directly affected both IBI and %EPT scores. Further sampling should provide more evidence as to whether benthic macroinvertebrate assemblages from these three stream systems are (1) consistently different with respect to habitat quality, and (2) negatively affected by construction of the DMPC.

^{*} Barbour, M.T., Gerritsen, J., Snyder, B.D., and Stribling, J.B. (1999). *Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates, and fish*, 2nd Ed., EPA 841-B-99-002, U.S. Environmental Protection Agency, Washington, D.C.

North Carolina Department of Environment and Natural Resources (2003). *Standard operating procedures for benthic macroinvertebrates*. Unpublished report by NCDENR, 44 pp.

Georgia Department of Natural Resources, unpublished data.

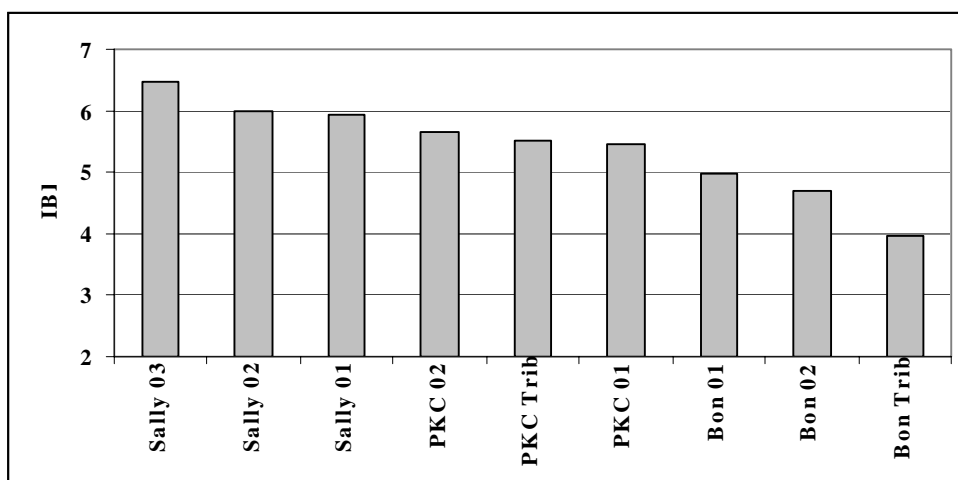


Figure 2-9. IBI scores for stream sites associated with the DMPRC (spring 2004).

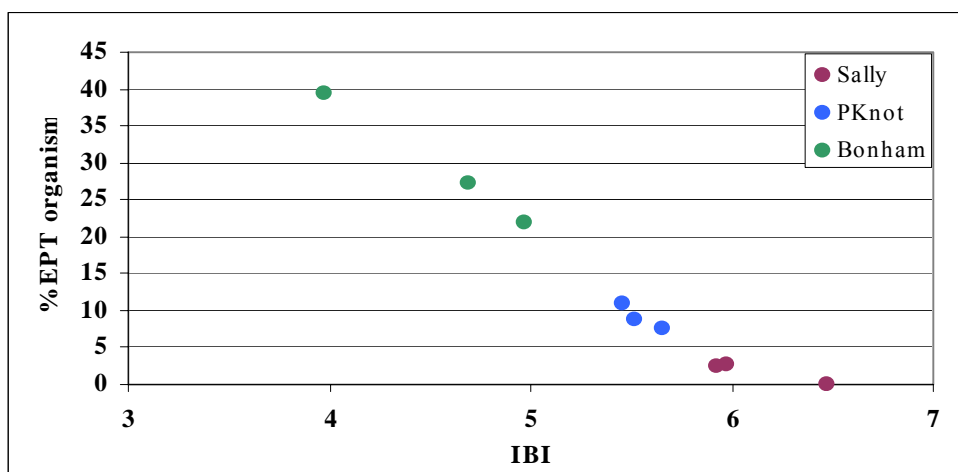


Figure 2-10. Negative correlation between %EPT and IBI scores for samples collected at stream sites associated with the DMPRC at Fort Benning (spring 2004).

Land Cover

We have generated landcover maps based on LandSat TM imagery from 1999 and 2001 and 2003. We used fragmentation statistical techniques to make comparisons between years based on forest area landscape metrics provided in Table 2-1. This type of metric can be used to determine the degree that a landscape meets specific habitat requirements for target species. In summary, the metrics below indicate that there has been a reduction in core forest area on Fort Benning; however, the change has not been as significant as the change outside Fort Benning within the Hydrologic Unit Code (HUC). The monitoring team has prepared a manuscript (accepted for a refereed journal) that developed the relationships between changes in forest habitat and habitat requirements of native song birds of the region that are dependent on interior forest habitat.

Table 2-1. Fort Benning forest area landscape metrics.

Inside the Installation	1999	2001	Change
Forested Area (ha)	50,897	51,516	619
Number of Patches	510	775	265
Core Area (ha)	29,279	25,916	-3,363
Edge Density (m/ha)	45	56	11
Outside the Installation (HUC)	1999	2001	Change
Forested Area (ha)	53,420	53,027	-393
Number of Patches	1503	2585	1082
Core Area (ha)	27,531	20,565	-6,965
Edge Density (m/ha)	41	58	17

Urban Encroachment

Urban encroachment and its negative impacts is not just a problem for military installations. In general terms, forest fragmentation caused by urbanization and sprawl poses one of the most significant, permanent threats to forests in the southern United States. As a result, this trend has the potential to be the biggest single threat to forest sustainability in the South over the next 20+ years. The population of the United States has roughly doubled between the late 1950's and 2000, and the population of the South has grown at an even faster rate. The share of the United States population living in the South grew from 30.7 percent in 1990 to 32.5 percent in 2000. By the year 2040, about 31 million forested acres are expected to be converted, concentrated primarily along the coast, in the Piedmont, and around major metropolitan areas.*

In addition to impeding military operations and deforestation of natural ecosystems, increased urban growth can provide pathways for invasive species, diminish some aspects of biodiversity (including threatened and endangered species), accentuate the risk of catastrophic wildfire at the wildland-urban interface, and could ultimately influence future water supplies.

Urban features were extracted from the satellite imagery for the past three collection years. Figure 2-11 illustrates the urban expansion over time (1999-2001-2003) for the metropolitan areas affecting Fort Benning. To remain consistent with prior

* USDA Forest Service. Southern Research Station. Asheville, NC. 2004. Internet Website: www.srs.fs.usda.gov.

urban growth estimates, urban features within the cantonment areas of Fort Benning were included with the final delineation estimates for all years. The results (represented as total area in hectares) were then analyzed to correspond to the urban growth impacting Fort Benning. There has been a steady increase in urban growth since 1999. Table 2-2 summarizes the growth estimates as well as the percentage of growth from the first initial estimate in 1999 to the present in 2003. In reference to Table 2-2, urban growth has increased roughly 2.5 percent from 1999 to 2001 and slightly more at 2.8 percent from 2001 to 2003.

Table 2-2. Urban growth estimates for metropolitan areas affecting Fort Benning.

Year	Total Area (ha)	Growth Percentage
1999	15,246	-----
2001	15,644	2.54%
2003	16,101	2.83%

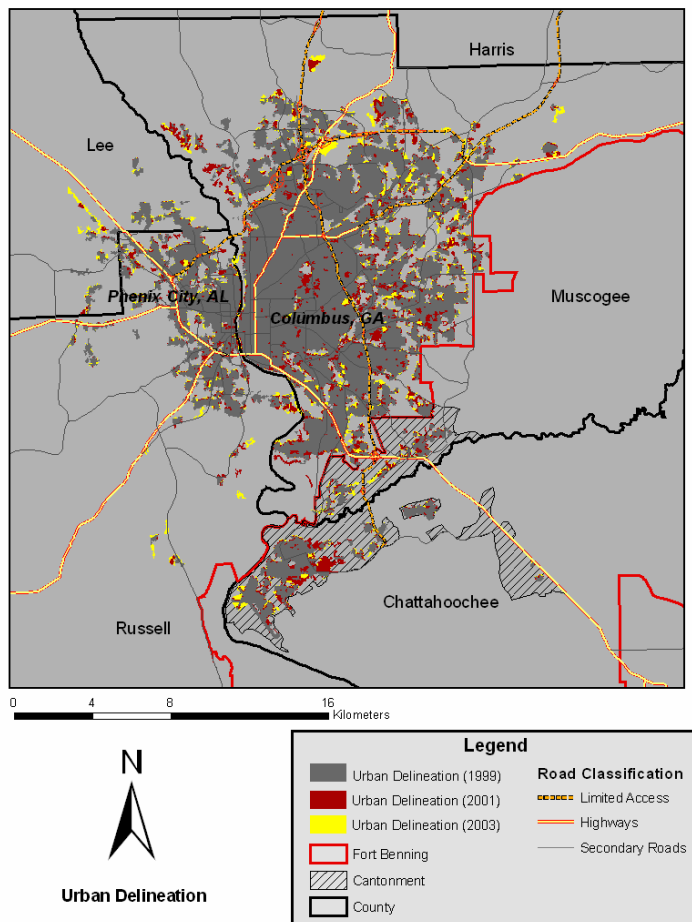


Figure 2-11. Urban expansion over time (1999-2001-2003).

The assisted feature extraction method utilized in this project demonstrates the advantages of the Feature Analyst^{*} software to provide the user with an easy way to extract urban features from satellite imagery without using the traditional image processing techniques. Other advantages of using the feature extraction software are that it is incorporated into ArcGIS 9.0, it is quite user-friendly, and it produces results fast.

The completed output (ESRI shapefile) from Feature Analyst can be easily compared to previous years to effectively determine where urban encroachment is occurring. This approach appears to be very helpful and efficient in a decision support system, especially for generalizing urban growth and its potential impacts. The feature extraction software provides the user with a quick and easy method to extract single features from the satellite imagery. However, using high-resolution satellite imagery, as opposed to coarse-resolution, may provide more precise estimates when using semi-automated feature extraction software such as Feature Analyst to extract detailed urban features. Similar to why high-resolution imagery is unsuitable for input into traditional pixel-based clustering and classification algorithms, coarse-resolution imagery may not be the best input for sophisticated feature extraction software that relies on a finer spatial context based on pixel size.

Woody Productivity

The woody productivity component was implemented during FY03 in cooperation with the Fort Benning Land Management Branch (LMB) personnel. Woody productivity is being derived, in part, using data from the Forest Inventory procedure used by Fort Benning personnel. Additional data are also available from SEMP research projects on Fort Benning. The procedure will provide watershed-level and installation-wide estimates of woody productivity and will support both the installation and research group needs. During summer 2003, forest inventory data were collected in the Delta 14 and 15 compartments that represent a portion of the area where long-term monitoring is being conducted. Estimates of standing woody biomass were estimated and provide the baseline productivity measure (Table 2-3). Data from additional compartments will be provided to the monitoring team as they are collected per Fort Benning's inventory schedule.

^{*} Feature Analyst is a product of Visual Learning Systems, Inc. PO Box 8226 Missoula, MT 59807.

Table 2-3. Standing woody biomass (baseline productivity) measured in green weight (lbs) per acre at compartment level.

Compartment	n(Plots)	Total Acres	Biomass (lbs./acre)
D-4	50	500	135,441
D-5	65	674	133,983
D-12	97	951	70,203
D-17	78	799	86,896

SEMP Monitoring Publications

Journal Articles

Submitted

Guilfoyle, M., S. Anderson, and S. Bourne. Trends in Habitat Fragmentation and Forest Birds at Fort Benning, GA. Ecological Indicators. (Submitted August 2004)

Lee, A., K. Randall, and R. Kress. The use of Rapid Bioassessment Protocols (RBP) in long-term Monitoring. Federal Facilities Environmental Journal. (Submitted August 2004)

Technical Reports

Published

Bourne, S.G., and M.R. Graves. 2001. Classification of land-cover types for the Fort Benning ecoregion using Enhanced Thematic Mapper data. ERDC/EL TN-ECMI-01-01. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Graves, M.R. 2001. Watershed boundaries and relationship between stream order and watershed morphology at Fort Benning, Georgia. ERDC/EL TR-01-23. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Graves, M.R., and S.G. Bourne. 2002. Landscape pattern metrics at Fort Benning, Georgia. ERDC/EL TN-ECMI-02-2. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Hahn, C.D. 2002. Evaluation of ECMI instrumentation deployed at Fort Benning. ERDC/EL TN-ECMI-02-1. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Hahn, C.D. 2001. Ground control survey at Fort Benning, Georgia. ERDC/EL TN-ECMI-01-02. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Hahn, C.D., M.R. Graves, and D.L. Price. 2001. S-Tracker survey of sites for long-term erosion/deposition monitoring. ERDC/EL TR-01-18. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Hahn, C.D., and D.L. Leese. 2002. Environmental data collection at Fort Benning, Georgia, from May 1999 to July 2001. ERDC TR-02-3. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Jackson S.S., and S.G. Bourne. 2004. "An Automated Procedure to Monitor Urban Encroachment Over Time on Fort Benning Military Installation" SERDP Technical Notes Collection, ERDC/EL TN-ECMI-04-01, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Kress, M.R. 2001. Long-term monitoring program, Fort Benning, GA; Ecosystem Characterization and Monitoring Initiative, version 2.1. ERDC/EL TR-01-15. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

Submitted

Jackson, S. S., S.G. Bourne, and M.R. Graves. Classification of Land-cover Types for the Fort Benning Ecoregion Using Enhanced Thematic Mapper Data: January 2003 Imagery. ERDC/EL TN-ECMI-04-X. (Submitted October 2004)

Lord, E. and S. Bourne. SEMP Data Repository Users Manual. ERDC/EL SR XX-XX, U.S. Army Engineer Research and Development Center, Vicksburg, MS. (Submitted September 2004).

Challenges

The process of transitioning the SEMP long-term monitoring technology to Fort Benning and other DoD installations as well as cost reductions for long-term monitoring will be initiated during FY04 with a scheduled completion in FY06. Close coordination with the SEMP technology transition team and the SEMP research teams will be required to facilitate this process.

3 SEMP Knowledge Management Plan

20 April 2005

Chris Rewerts

Previous to 2004, the SEMP Repository was designed and operated as the primary framework for managing SEMP “knowledge”. While the repository was successful as a web-based organized software environment for transfer and maintenance of research data, the repository does not encompass all the different information types relevant to SEMP, nor was this framework sufficiently robust to allow SEMP data to be easily queried from external sources or easily linked to other related repositories. Thus, a decision was made, which has since been affirmed by the RAND review, to develop a more comprehensive plan for management of all phases and types of SEMP knowledge. A draft version of this plan is provided as the following.

Purpose of This Plan

The purpose of this plan is to identify steps that facilitate the coordinated, enterprise-scale capture, sharing, and analysis of all relevant data and information generated from SEMP or about SEMP for (1) use in conduct of future SEMP research and monitoring and analysis efforts, (2) use in providing easy access of SEMP information to host site(s), (3) collaboration and sharing with others, beyond SEMP and the host site, and (4) use in mapping the known and unknown entities and relationships of Southeastern/Sandhills Fall Line ecosystems and the dynamics of these ecosystems by research teams, land managers, regional partnerships, stakeholders and others.

This plan considers the current status of the SEMP Data Repository (SDR) with emphasis on issues raised in the report created by a study performed by RAND (see Addendum, page 48) and anticipates a larger vision of how the repository and its website could provide much more function within the ecosystem research initiatives such as SEMP, some of which is technically possible but hasn’t been done yet. Thus, in the future, the SDR could be a subject of its own area of research – one that we call “Ecosystem Knowledge Mapping.”

Background of the SEMP Data Repository

To understand where we can be potentially evolving the SDR, we need to examine and understand how it began. In this section we examine the design goals of the original version of the SDR and the redevelopment performed in 2003. This will provide the basis of understanding what will be required to consider the comments from the Rand Report as well as a strategy to bridge toward the concept of Ecosystem Knowledge Mapping.

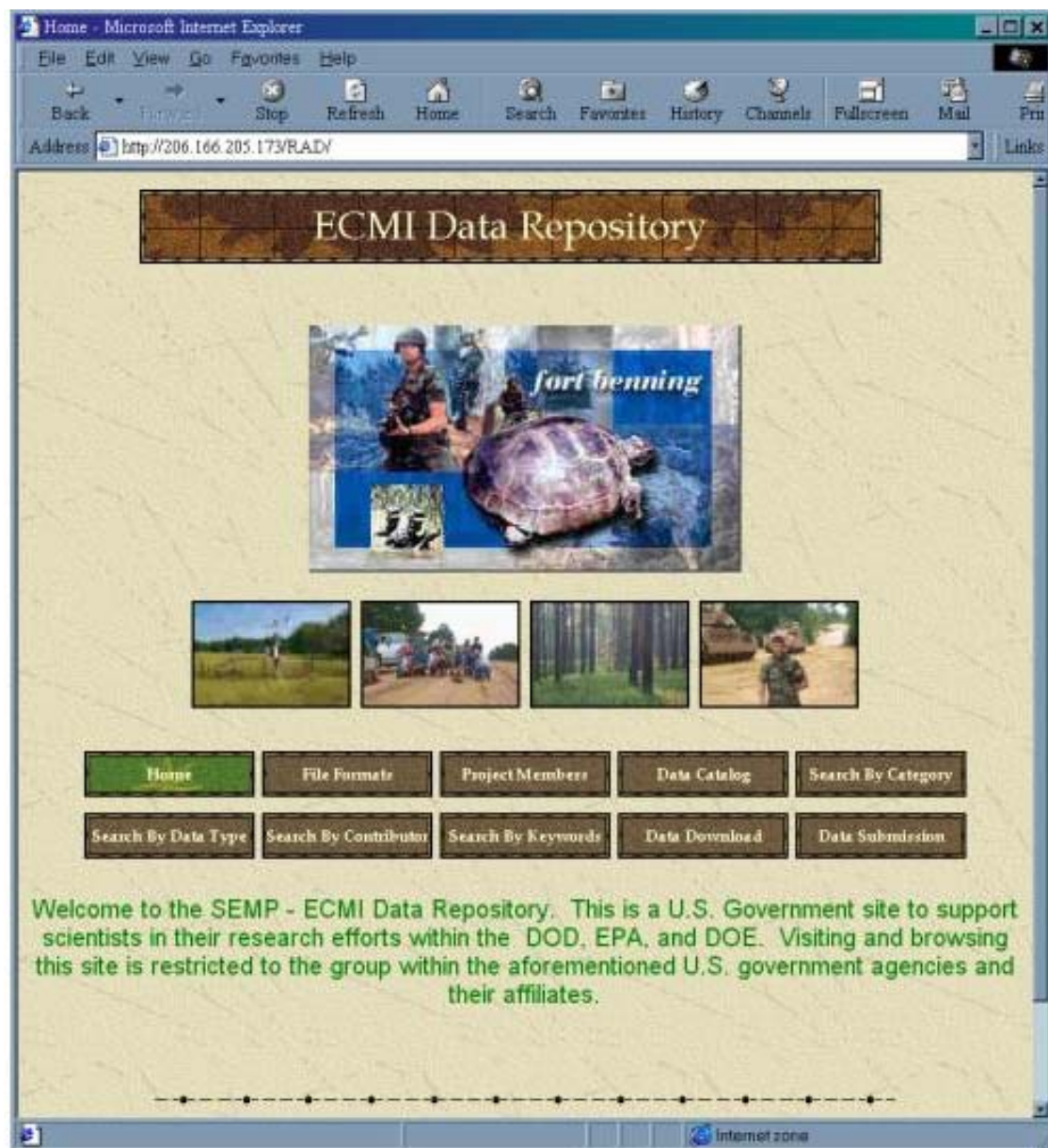


Figure 3-1. Screen capture image of the original SDR web page.

The original design of the SDR (Figure 3-1), as outlined in the SEMP Annual Reports, was as follows:

1. Create a simple and functional means to provide data exchange among SEMP study partners. The teams initiating research would need numerous forms of basic data to plan and carry out their projects. Although much of the available data not being developed by SEMP could be obtained from Fort Benning, it would be more efficient for researchers and Fort Benning personnel alike if these data were collected in one place, organized, and documented in a standardized way.
2. Create a long-term data archive to protect SEMP investment. Many times in research projects the deliverable from the project is in the form of reports or articles. Although valuable, they do not include the extra data and its provenance that represent a significant portion of the research investment. SEMP, by design, is a long-term research program and thus it is important to collect, document, and archive not only the end results of the research but the significant data collected and analyzed as part of the research.
3. Low long-term maintenance requirements. This is important as a design goal so that as much of the SEMP investment can go in to the primary goal of research. Therefore, one can see that to reduce labor costs the SDR is designed to be web-based so that it is, as much as practically possible, a self-serve kiosk for researchers and others to use with as little SDR staff as possible for day to day interaction with users.
4. Stand-alone archive or to act as a “node.” Although the SDR needs to be fairly self-contained so that it serves the SEMP community fully, it is still cannot be the only repository of ecological research even in its own ecosystem. Therefore the design needed to consider how it could be a node or peer among other similar data or research repository, such as the design model of many library or even Geological Information System (GIS) data clearinghouse websites.
5. Organized directory structure based on the Spatial Data Standards for Facilities, Infrastructure and Environment (SDS/FIE) entity set. This is a logical, if not mandated, data hierarchy to serve as the overarching logical organizational structure for the data, especially since much of the original data sets would be geospatial in nature.

It is interesting that also included in the original conceptual design were statements of what the SDR would not be. It is only natural to assume that these statements appear because there was discussion on these points:

1. Will not function as a graphic map product server.
2. Will not function as an enterprise level geospatial data warehouse for operational use at Fort Benning.

3. Will not be Relational Data Base Management System (RDBMS)–based, instead will be file based.

One can assume that the functionality described in these three points were considered too elaborate and expensive and thus in conflict with the other goals of “simple and functional” and “low long-term maintenance.” This is understandable, especially at the early phase of SEMP when these design goals were reported. What falls out in examination of the design goals is a practical design that builds a way to collect, document, and organize the necessary data for the initial phases of SEMP.

The practicality of the design was followed through in its method to make data available on the web. In the history of the Internet, one of the most useful and practical methods for data file exchange has been the File Transfer Protocol (FTP), which provided a way for a designated portion of a computer’s file system to be accessible to the rest of the Internet. For the SDR, the data would be arranged taxonomically on the file system according to the SDS/FIE organizational structure, as shown in Figure 3-2.

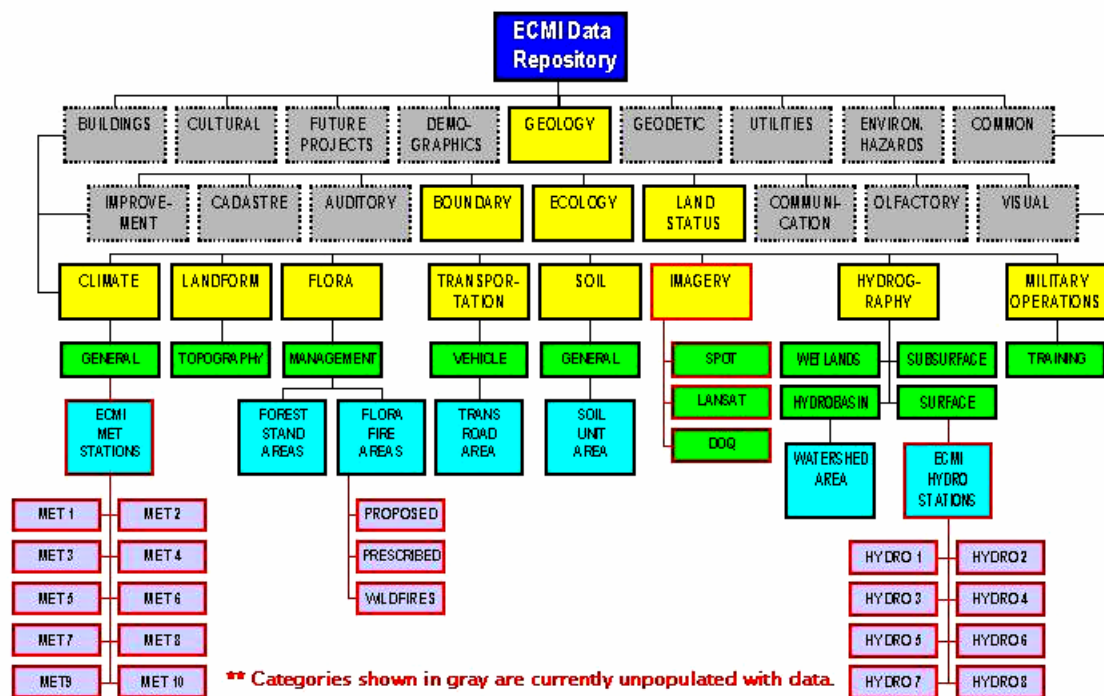


Figure 3-2. SDR data structure.

A simple web interface was created to overlay the file hierarchy. At the heart of this was a modest Microsoft Access Database that contained a data index of the files, and thus users could search the index for the desired files. The database also contained profiles for the SDR users.

In the early phase of SEMP, the SDR contents were as follows:

1. Baseline GIS data of Fort Benning and the surrounding area (e.g., forest stands, burn areas, training compartments, wetlands, geology, watersheds, soils, etc.);
2. Digital imagery of Fort Benning and surrounding area (digital ortho-quads, satellite imagery, etc.); and
3. ECMI monitoring data (e.g., ECMI meteorological weather station data and hydrologic surface water data, etc.).

The design anticipated additional data from SEMP research projects, as individual research projects continued, contributions to the SDR would include field data, analysis results and model output.

The 2003 Redevelopment of the SEMP Data Repository



Figure 3-3. Screen image capture of the current version of the SDR.

According to SEMP project reports, in 2003 the SDR was again redeveloped (Figure 3-3) and the previous data was ported to the new system. The original system had been implemented and hosted by an academic institution contracted for those services. The new version of the SDR was implemented and hosted on the Army Engineer Research and Development Center (ERDC) corporate "Web Farm." This new

system used the Windows 2000 Internet Information System (IIS) web server technology, with the programming of the web page functionality constructed using “aspx.net” language within the “.NET” framework technology. The look-and-feel of the site was fashioned after the SEMP web pages that were, at that time, hosted on the Defense Environmental Information eXchange (DENIX) web portal.

As part of the redevelopment, a login/password procedure was added to the website so that anyone creating a profile with a valid email could obtain a password. The system design included rudimentary user roles for the cursory control and documentation of data upload and download activities.

Users accessed data via a “Data Discovery” tool bar (Figure 3-4) that appeared in the web inter-face upon successful login to the system.

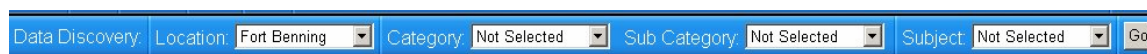


Figure 3-4. SDR website data discovery tool bar.

The data discovery tool bar was the web interface that provided users the primary means to locate data in the repository. The operation of the bar allowed users to “discover” data as it was organized in the SDS/FIE hierarchy. Thus, starting with the first selection on the left for “location” provided options for “Fort Benning” and “Sandhills Region”. This selection obviously was not necessarily the SDS/FIE, but logically allows the separation of data holdings related directly to the Fort Benning SEMP projects and other data or related research in the ecoregion.

As one selection on the data discovery tool bar is made, the system populates the next selection box with the appropriate selections for the previous selection, and thus the user can work through the organizational structure of the SDR data hierarchy. When a selection for a data object is made, the system provides the user with a “card catalog” page for the data object. An example is shown in Figure 3-5.



Figure 3-5. An example “Card Catalog” for an SDR data object.

The data object’s card catalog provides links to the data file, the metadata file, a descriptor of the data file type, and contact information for the owner of the data object.

Repository Database Schema

At the heart of the SDR is a Microsoft Access Database. This database contained data to control the function and look-and-feel of the website, user activity logs, user account profile information, and, most importantly, the index data about the repository data files. As with the previous version of the SDR, the actual data file holdings of the repository are stored on the computer file system of the web server, and the database index contains links to the files along with their index information.

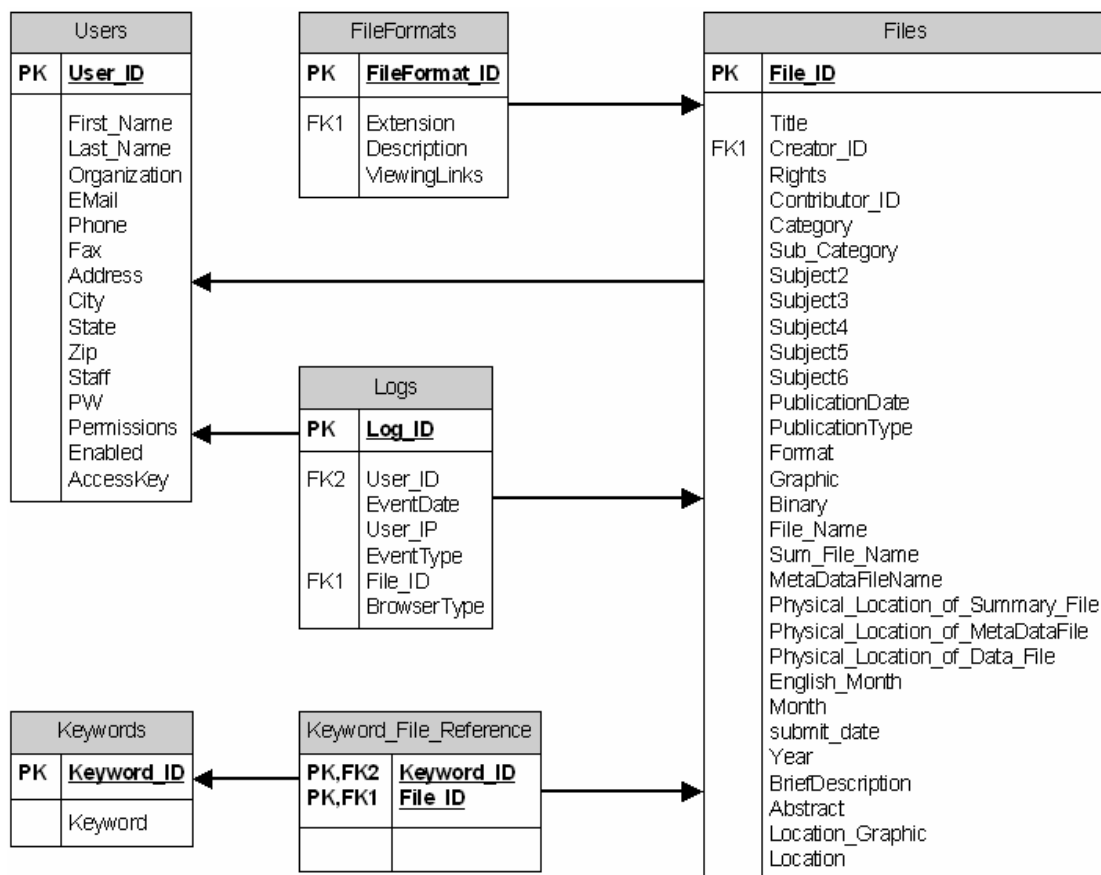


Figure 3-6. SEMP data repository database schema summary diagram.

Figure 3-6 shows the primary portions of the SDR database schema that relate to the database object files, user profiles, website logs, file formats, and key-words.

Observations and Commentary of the Current SEMP Data Repository with Suggestions for Future Changes and Enhancements

As SEMP research has progressed and researchers have been uploading their data to the repository, we can now take stock in how the system has performed overall. It is most important to be able to assess how well data holdings are documented and indexed as well as how this serves the users (especially those of the host installation) who are looking to provide for their needs. The following sections will examine the design and use of the repository. Comments are those of the author augmented with special consideration for many items are in direct response to the findings pub-

lished in Assessment of the SERDP Ecosystem Management Project (SEMP).^{*} Please see the Addendum of this section (page 48) for notes on direct references from the report that relate to the SEMP data repository.

Data Object Index Information

Data documentation is in the form of index data in the SDR database and metadata files uploaded to accompany the data files. Both types of data documentation are critical. The SDR database index information is important because it is the means for users to find data on the system as well as for the system to provide the archival of the holdings and control access. The metadata is important to document exactly what the data are, who created, at what scale, in what time period, with what methodology, and so on. If metadata are incomplete or inaccurate, it can mean that the data are less usable and thus without sufficient metadata, the data could be much less valuable, especially if contact to its creator is lost over time.

First we will examine SDR index data. Index data for a SDR data object is created by the user who uploads the file to the website using the form shown in Figure 3-7.

^{*} Lachman, Beth, Noreen Clancy, and Gary Cecchine. 2004. Assessment of the SERDP Ecosystem Management Project (SEMP). Restricted Draft. Prepared for SERDP by the Rand Corporation.

Upload Data

Creator
Anderson, Drew

Title

Give a brief description of this data:

Document File Name
Browse...

Meta data file name
Browse...

Which location?
Fort Benning

What category does this data best fit into? **Please click [here](#) for definitions of each category**
Boundary

Sub Category
Aquatic_Ecology

Subject
00_Images

Please select Keywords that best describe this data set

Available Keywords: Boundary Line, Burns, CERL, Chatahoochee, chemistry, Classification

Selected Keywords:

Publication Date

Data Type
Document/Text

What format is this data?

Abstract as to why this document is relevant to this repository.

Upload File

Figure 3-7. Screen capture image of the data file upload web form.

The following observations and comments are made based on an analysis of data observed in the SDR database table containing the index information entered by users.

Table 3-1. The primary fields used to index data uploaded to the SDR.

Field	Description	Comment
Title	Text entered by user	Text content is free-form
Contributor ID	Login of user completing the form and uploading data	Automatically entered by system based on login
Creator ID	Selection from system user table of the data creator	By being set by the Contributor, this allows a third party to upload data for the Creator (e.g. by an assistant or team member)
Location	Selection of "Benning" or "Sandhills"	
Category	Selection from the list of data categories	e.g. Climate, Hydrology, Geology, Flora, Fauna, etc
Sub-Category	Selection from the list of sub-categories relative to Category selection	
Keyword(2-6)	Multiple selections of keywords can be selected.	Keywords are arbitrary: 1) not standardized; 2) not required
Publication Date	User entered	Date is arbitrary: 1) format not delineated; 2) "Publication date" unclear - could mean when data collected, uploaded, or ?)
Publication Type	Selection from a list, e.g. GIS, Imagery, Tabular, Text	No automated checking is done to determine accuracy of entry
Format	Filename extension list (e.g. *.xls or *.pdf)	Could be collected/determined automatically and checked against a known list of file types
Filename/location	Where the uploaded file is being stored by the system	Determined by the Category/Keyword description(s) chosen by user
Metadata file-name/location	Stored in same location as data file	Metadata file is not required.

Table 3-1 represents the primary fields used to index data uploaded to the SDR

Based on observations of the index information about the data objects currently in the SDR database, it can be seen that there is room for improvement. Although there is a trade-off between keeping the upload process simple enough so that it does not overly encumber the users, but rich enough so that the index information is accurate and detailed sufficiently to identify resources. If the repository is to provide means for users to discover data and other resources, the system's information about those resources should be accurate, robust, and compliant with applicable standards.

Of the index fields currently being collected, the system should do more checking to ensure required fields are properly completed. There is also additional index information that should be required that is not currently being collected, including temporal (for example, date of original upload, date of last change to the uploaded data or index information, date of data collection, and date of data publication); spatial information (such as two sets of coordinate pairs that define the rectangular spatial

ex-tent that contains the data object's relevance or origin); and rights or distribution permission. Keywords are another component that would benefit from re-examination. The current keywords are rather arbitrary and certainly not part of any standard thesaurus or ontology.

Overall, a complete assessment for needs for index data should be performed by cross-walking SEMP data object requirements with other standards for metadata, such as Dublin Core, SDS/FIE, FGDC, and/or those used by other ecological research groups with which it is relevant to share resources.

Data Object Metadata Information

The database index information discussed above is one means for SDR users to characterize data objects. The other method used in the current SDR design and function is metadata files that can be optionally uploaded with the data file by submitter. Metadata files are meant to describe the data. There are a number of issues that have been observed about the design and practice of handling metadata in the SDR.

For the types of data currently in the data repository, metadata standards are most well defined for GIS data layers. Most GIS are in formats created by or compatible with ESRI GIS tools (such as Arc/Info "coverages" or ArcGIS "shapefiles"). Since ArcGIS includes tools to create standards-compliant metadata files, their creation for use with the SDR is straightforward. According to ECMI reports, the metadata standards for geospatial data were adapted as practical for the data generated by that project's monitoring initiative. As noted previously, in the early phase of SEMP, the SDR content were as follows:

1. Baseline GIS data of Fort Benning and the surrounding area (e.g., forest stands, burn areas, training compartments, wetlands, geology, watersheds, soils, etc.);
2. Digital imagery of Fort Benning and surrounding area (digital ortho-quads, satellite imagery, etc.); and
3. ECMI monitoring data (e.g., ECMI meteorological weather station data and hydrologic surface water data, etc.).

All of these data appear to be accompanied by excellent metadata. These data, for the most part, were collected and prepared either by or in direct cooperation with the previous managers of the SDR. Other data that were uploaded, such as those uploaded by the research projects, have varied quality of metadata. Most of these metadata have arbitrary format and content. It appears that emphasis was placed on data being uploaded to the SDR but the data metadata format and content was probably not reviewed. Incomplete documentation/metadata severely threatens the

usefulness of data for future use, and thus undermines the investment in the research that created it. The format and content of metadata is not overtly obvious to the SDR user, although recommendations for content were probably given to researchers during SEMP meetings or other processes. It also should be noted that the upload system used by the SDR allows data upload without metadata, so the system is reliant on the knowledgeable, good behavior of its users.

Data “Discovery” versus Data Search

Probably the most notable weakness of the current SDR design for metadata how the information is stored – in nonstandardized, individual documents on the SDR file system. This is a weakness because users must first find the data, then download and read the metadata file (if it exists and is useful) to learn about the characteristics of the data so they can know if it is indeed what they are looking for.

At this point in the discussion of the SDR, it is appropriate to note that the system provides no means to openly search for content. The only means provided is to use the “data discovery” tool bar as described above, which means a user must, in a sense, play the game “20 questions” with the system, working through the categories in their attempt to find a given data object, if it exists. Of course, if the data object was inaccurately classified in the index when uploaded, the chances of the user finding data they need is greatly reduced.

This discussion has already identified that a search for data could be enhanced by improving the quality and quantity of the index information stored in the database describing uploaded data objects. If instead of entering metadata information in flat files, part or all of those metadata were also stored in database fields and consolidated with the index information, the metadata fields would be easily searchable. In addition the SDR would benefit if data keywords were more standardized, either to a thesaurus appropriate to SEMP or the Southeast United States ecosystem, or to acceptable thesauri or ontology available from other groups (allowing for better searching/sharing of data with collaborators).

Data Review Process Suggested

Further consideration needs to be given to the review of data uploaded to the SDR. With no review, too much is left to chance that quality of data, metadata, or the data index documentation is incomplete, inaccurate, or substandard. For the highest standards to be obtained, SEMP could put in place a peer-review process of some of the research data to be placed in the repository. Another possible means to review data is for SEMP program or science managers to be assigned the task of reviewing data as part of the review process for research contract deliverable account-

ability. SDR administrators could also be given the task. However, since their focus and specialization may be more toward the development, operation, and maintenance of the website and data repository, they may not have the specialized understanding of the research processes to be able to fully evaluate the quality of data and its documentation.

Repository Administration

SDR administration has been transitioned from ERDC-WES to ERDC-CERL. Anticipating and preparing for a redesign of the repository, we have established a secondary prototyping website for development and testing of features so that current repository function can be uninterrupted. To help analyze data indexing, search, and systematic sharing of data with others, a project has been initiated to investigate the use of software and protocols from the Open Archives Initiative.

We are re-evaluating the design for roles and permissions for database users and data types, so that we can build functionality to enable and enforce roles. This will help to enable compliance with Federal rules and mandates for data as well as for website administration and security. This will also help to create confidence on the part of researchers that if they upload data, they can sufficiently restrict access to the data per their needs. Information Assurance is the area of work associated with ensuring and protecting three critical aspects of information:

- Availability - making sure that information is accessible by those who need it when they need it.
- Integrity - making sure that the data is valid and protected against unauthorized alteration.
- Confidentiality - making sure that the information is available only to those who have the proper clearance and need-to-know.

We are performing a redesign of the reporting functionality based on SEMP management requirements.

Ecological Research Project Database

The SDR administration and management will continue and refine ongoing collection and upload of data to the current repository while the redesigned system is in progress. In addition, the redesign will include the addition of documentation of SEMP research and other collaborative or relevant research projects (such as those funded by Fort Benning) in the central SDR database. Project data can be updated

by the researchers so that status and factsheet-relevant information can be kept up to date and available.

Web Interface

Previously the SDR was separate from the SEMP website where generalized information about SEMP and its projects were made available to the general public. These sites will be consolidated so that the SDR will serve as both data repository and website for SEMP. As part of this process, other changes are important, such as taking measures to conform the website to relevant Army and DoD requirements for websites.

SEMP Document Management

The primary efforts of the SEMP repository effort at this time have been focused on the addition of document management. To this point SEMP has generated a large quantity of documents that should be indexed and stored to help preserve the knowledge and document the administration of the program and individual projects. A standalone database was designed and built to for the purpose of indexing the collection of documents. In the future, this database and the documents will be merged data schema and data with new SEMP repository database to be developed. Documents for SEMP research project will be linked in the database to the project and to the researcher profiles to facilitate logical access as well as project tracking and management.

It should be noted that SEMP should emphasis to researchers to obtain rights to publication, such as journal articles published as a part of the project, so they may be made available via the SDR.

Connecting SEMP With Other Entities

While it is prudent for SEMP to provide a formal and overt process and structure to archive the process and results of its research program and make it readily available to the Fort Benning installation and its partners, it is also important to share data and results with the larger community. The primary means to do this will be accomplished by focusing on the issues of data object index and metadata issues discussed previously, especially if the standards are cross-walked with those used by other ecological research and data repository efforts. This can facilitate such shar-

ing and outreach methods such as uploading SEMP metadata to federated clearing-houses such as the USGS National Biological Information Infrastructure (NBII).

The other preparation to accomplish sharing and outreach will be included in the website redesign. Firstly, a redesign should allow browsing of web pages, and public information without a login. Next, issues of user roles and data access need to be examined and addressed so that public data can be made easily found and accessed by the public and data with restrictions can be properly handled.

Needs for Fort Benning have been highlighted by the Rand Report and there are many opportunities to better enable communication, data access, and technical transfer using the SDR. This project will work with the installation personnel to define and address issues.

Ecosystem Knowledge Mapping

The current goals of SEMP Knowledge Management have been outlined in this report starting with the background of the SDR and focused on the key issues to build a solid foundation that will insure security and functionality of the system as a data repository. The primary expansion proposed adds documents to the repository, data and information about projects, as well as website functionality that was previously maintained elsewhere.

It is also important to note that this work will also be looking toward to a future vision we call “Ecosystem Knowledge Mapping” that can logically build upon the foundation the document outlines. The key questions that Ecosystem Knowledge Mapping will address are:*

- How can we make scientific knowledge and data (such as the outcome of these projects and their data) readily usable by natural resource managers who could benefit from the knowledge to make decisions?
- How can we better enable our researchers to communicate, collaborate, and contribute to our collective scientific knowledgebase?
- How can we better organize and represent the goals and drivers of natural resource managers so we can better target our research on their needs?

* Rewerts, Chris, William Goran, and Pamela Sydelko. Ecosystem Knowledge Mapping to Support Military Lands. In Proceedings of: 8th World Multi-Conference on Systemics, Cybernetics, and Informatics, 18-21 July 2004, Orlando, Florida.

- How can tools we use to facilitate collaboration and communication also capture content that will help document how and why decisions were made?

With the proposed foundation of the repository functioning, Ecosystem Knowledge Mapping (EKM) research can explore thrust areas such as the following to address the above questions:

- Knowledge extraction — harvesting what we know from data, human experience, scientific literature, and other sources.
- Knowledge and data representation — how to encode knowledge elements so they are computable, self-describing standardized formats.
- Knowledge and data ordination — quantifying knowledge representation ontologies according to scales such as spatial, temporal, scale, biome, administrative, etc.
- Knowledge and data repositories — how to collect, store, mine, share, combine, while accounting for provenance.
- Relationship mapping — how to connect relationships of information among and between ontologies to better discover, access, share, and synthesize knowledge.
- Primordial models — how to capture knowledge about ecosystem processes in to computable components.
- Simulation support — how to create a framework where computable components can be agilely combined to support ecosystem research and management.

Geospatial Functionality

Throughout the history of the SDR that was reviewed as part of this work, there were numerous mentions of geospatial tools used as part of the SDR. As noted in the background, the original design explicitly ruled out the SDR being an enterprise GIS for the installation or an interactive web mapping tool. There are a number of reasons why this would be useful and also a number of reasons why this can be problematic. One of the issues that need to be resolved before this can be considered is how the Army Headquarters regulations for geospatial data and systems, currently in draft, will be written. For instance, public access to installation GIS data may come under the direct control of the Army HQ, and the only web access to these data could be through its proposed GIS repository. Thus, for at this time, it is prudent to table plans for this type of functionality of the SDR until the regulations are finalized.

Note that the current proposed redesign related to metadata does have relevance here, since part of the metadata that should be part of the data object's searchable

metadata is geographical extent. With this change in place, documents and data can be searched by location as well as, or in combination with, other search characteristics.

Knowledge Mapping, Data Discovery, and Visualization

Other components that can be considered part of EKM are advanced tools for data discovery and visualization. While not proposed as an immediate plan to be executed, it is part of a vision that guides the planning of the redesign of the foundational elements of the SDR. Part of the vision is to expand upon the metadata and keyword thesauri so as to build or add to ontologies of the knowledge domains encompassed by SEMP research, to enable making the knowledge and data of SEMP more “computable” using technologies of the semantic web. These emerging technologies include means to better search, share, and visualize the knowledge holdings and the knowledge universe. As such the EKM vision is also a path to better enhance the technology transfer of SEMP research to its customers.

Reference Websites

The following are part of a representative selection of related efforts to collect, archive, share, and add value to ecological data and knowledge — similar to the proposed function of the SEMP Data Repository and Ecosystem Knowledge Mapping Initiative. As such, they must be engaged to find how to collaborate and leverage efforts to bring the most value possible to the SEMP, its stakeholders, and regional interests.

National Biological Information Infrastructure (NBII). <http://www.nbii.gov>

National Ecological Observation Network (NEON), Southeastern Region.
<http://www.uga.edu/srel/Neon>

Science Environment for Ecological Knowledge (SEEK).
<http://seek.ecoinformatics.org/>

Sustainable Sandhills (with Fort Bragg, NC, as a central stakeholder and participant). <http://www.sustainablesandhills.org> ; Also the related North Carolina Sandhills GIS Database. <http://www.sandhillsgis.com/sandhillsgis.htm>

Addendum: Data Repository-Related Lessons Learned from SEMP

A SERDP-sponsored third party assessment of SEMP was conducted in the previous year and provides a number of observations and recommendations relevant to design and operation of the data repository. The evaluation, assessment, and redesign elements of this report have taken the observations and recommendations of this report into consideration. The following are comments extracted from the report, categorized by topic, and referenced by page number from the report created by Beth Lachman, Noreen Clancy, and Gary Cecchine of the RAND corporation (Assessment of the SERDP Ecosystem Management Project (SEMP)). Please note the references were made to the September 2004 draft version of the report, and some shifting of page numbers may occur in the final report.

1. Repository Administration

p. 137: The need is identified for designing roles and permissions for users.

2. Web interface

p. 137: Need for roles and permission taxonomy w/r/t data/document access.

3. SEMP Document Management

p. 92: Relevant documents, namely INRMP and SEMP Background should be made available on repository website.

p. 135: Need to provide communication and document management support.

p. 136-137: There are some specifications provided for document collection and a database for their management.

p. 137: Acquire journal articles (and rights).

p. 137: Prepare a standard amendment so the PI/researcher can obtain rights and permissions for articles so they may be made available to repository users.

p. 139: Collect and track information and documents for presentations that PIs/researchers make at non-SEMP venues.

4. SEMP Project Metadata/Management

p. 30: What tools can provide infrastructure support to the field research at the installation.

p. 60: Link to real/live data.

p. 61: e.g., Water data can be GIS linked to watershed context.

5. GeoTool: web-based GIS functionality

p. 30: Provide an infrastructure to support field research.

- p. 65: Performance outcomes of projects should be linked to SON [this could be facilitated with by integrating with tracking of project].
- p. 75: Need to provide better project information to TAC. Not just proposal, but what was implemented by the project after award.
- p. 93-94: Discussion of what should be in project data.
- p. 107: Work with installation to determine their needs [that can be met through project metadata/management].
- p. 135: Project tracking is needed.
- p. 140: Annual report for PI/researcher to be completed online . [This will also help to make the submitted data/information more computable].

6. Knowledge Mapping, Data Discovery and Visualization

- p. 40: Discusses a need to ordinate to the Strategic Plan.
- p. 48: [Relates to ecological ordination]. There are 15 unique ecoareas at Fort Benning.
- p. 103: Discusses a need for broader approaches to be employed for technical transfer [not only Indicators approach].

7. Other Efforts

- p. 39: Need for QA/QC for aspects of SEMP — what organization(s) can SEMP establish relationships to provide collaboration and peer review?
- p. 98: Discussion of working with others.
- p. 108: What does Fort Benning/SEMP need to share with others?
- p. 137: Recommendation to include other effort's data/information/links on Repository.
- p. 137: Provide platform that facilitates the formulation of research gaps and creation of SONs.

8. Other needs of the installation

- p. 30: Infrastructure for managing/coordinating field research on installation.
- p. 32: Connect weather and for other potential uses on the installation (e.g., prescribed burning).
- p. 107: Recommendation for a repository POC/administrator at Fort Benning.
- p. 107: Provide demonstration and training for installation persons whose tasks could be supported by the Repository.

4 Determination of Indicators of Ecological Change — 1114A

2004 Annual Report

PI/Institution: Dr. K. Ramesh Reddy, University of Florida, Gainesville, FL

Collaborators: Wendy Graham, Department of Agricultural and Biological Engineering; Jennifer Jacobs, Department of Civil and Coastal Engineering; Andrew Ogram, Department of Soil and Water Sciences; Deborah Miller, Department of Wildlife Ecology and Conservation; Joseph Prenger, Wetland Biogeochemistry Laboratory; Suresh Rao, School of Civil Engineering, Purdue University; George Tanner, Department of Wildlife Ecology and Conservation

Project Duration and Funding

FY99 (\$K)	FY00 (\$K)	FY01 (\$K)	FY02 (\$K)	FY03 (\$K)	FY04 (\$K)
400.0	404.0	409.0	402.0	258.0	156.6

Project Status

Work completed September 2004. Funds discontinued beyond FY04. Project close-out brief and final report due December 2004.

Introduction

The goal of this research is to develop indicators of ecosystem integrity and impending ecological change that include natural variation and human disturbance. We are evaluating parameters related to properties and processes in the understory vegetation, soil and surface hydrology as potentially sensitive indicators of ecosystem integrity and ecological response to natural and anthropogenic factors. The basic premise is that soil serves as the central ecosystem component that links the quality of the terrestrial habitats (by influencing vegetation and its stability) and the aquatic habitats (via control of soil erosion and overland runoff). Our research and monitoring plan addresses the following objectives:

- Identification of physical, chemical and biological variables of soil, surface hydrology and vegetation that may be used as indicators of ecological change.

- Evaluation of potential ecological indicators for sensitivity, selectivity, ease of measurement and cost effectiveness.
- Selection of indicators that (1) show a high correlation with ecosystem state, (2) provide early warning of impending change and (3) differentiate between natural ecological variation and anthropogenic negative impacts.
- Determination of the range of natural variation for indicator variables, and comparison with the range of values under anthropogenic, especially mission-related, influences.

Background

The concept of ecosystem integrity, or “health,” in the context of the military installation, encompasses not only the sustainability of the “natural” biota in the system, but also the sustainability of human activities at the installation, primarily the military mission. Thus, changes in ecological condition are of great concern to both resource managers and military trainers. A suite of variables is needed to measure changes in ecological condition. Two types of indicators that may be useful are (1) variables that inform managers about ecosystem status and (2) variables that signal impending change.

Objective

The goal of our research is to develop suitable indicators of ecosystem integrity and impending ecological change resulting from both natural variation and anthropogenic activities. We will identify physical, chemical, and biological properties and processes that reflect ecological condition and change in intensively and lightly used ecosystems on the Fort Benning military installation.

Approach

The University of Florida – Purdue University research team is employing a multidisciplinary and multi-scale approach, which will result in robust techniques for ecosystem monitoring and evaluation. We are evaluating a suite of parameters related to properties and processes in the soil, understory vegetation, and surface hydrology as potentially sensitive indicators of ecosystem integrity and ecological response to natural and anthropogenic factors. In general, the soil hydrologic and biogeochemical parameters to be examined relate to changes in soil physical and chemical characteristics, and the response of soil microbial population and plant communities.

Accomplishments

Severe impacts to soil, vegetation, and hydrologic processes are associated with mechanized training involving tracked (tanks and Bradley) vehicles. Moderate to severe impacts also occur in several areas of non-military land use, primarily due to forest clear-cutting activities. Hydrologic and ecological impacts observed in wetlands and streams downslope from clear-cut upland areas were similar in nature to those observed in association with severe military disturbance; however, since silvicultural activities are typically shorter duration, the extent and severity of these disturbances are less and recovery more rapid than those associated with mechanized military activity. The soil, vegetation, and hydrologic parameters (potential indicators) that were most closely correlated with predetermined site disturbance levels (low, moderate, severe) were those that reflected loss of vegetation biomass and community structure, disruption, and/or compaction of soil, and loss of soil A horizon (and soil organic matter) in uplands; and accelerated sedimentation of clay and sand in wetlands. In wetland areas downslope from impacted uplands, relationships between soil biogeochemical indicators and upland impacts were less clearly defined. However, indicators that directly related to wetland soil organic matter content (and “dilution” by clay or sand) were useful in identifying sediment-impacted wetlands located below severely-disturbed upland areas. The potential value of wetland soil biogeochemical properties as indicators of nutrient loading in uplands (e.g., from excessive fertilization or waste disposal) was not realized at the Fort Benning study areas, due to the nature of the ecological impacts in upland areas.

Commonly observed impacts of mechanized training on soil and vegetation included:

- Disturbance or destruction of vegetation communities, including ground cover (especially litter cover), understory and canopy vegetation.
- Disruption of soil A horizon and effective burial or dilution of biologically-active topsoil with organic-poor lower horizons.
- Compaction of subsoil, reducing soil permeability and increasing runoff and erosion potential.
- Loss of A and E horizons in severely-impacted upland areas, rendering soil unsuitable for supporting native plant communities.
- Gully erosion in downslope areas, with significant sedimentation in wetlands and streams.
- Short-circuiting of watershed flow paths with increased surface runoff and decreased subsurface detention in uplands (creating hydrologic and ecological imbalances in wetlands and streams).

Soil Biogeochemistry

The most promising soil biogeochemical indicators for upland areas were highly correlated with soil organic matter content and carbon (C) quality (biodegradability):

- *Total organic C - indicator of soil disturbance resulting from loss of topsoil (erosion) or mixing of A and E horizons.*
 - Level of military impacts affected soil C and N storage, as well as microbial parameters. For example, TC was about 4 times higher in the low impact upland transect than in severe impact transect. This difference was even higher for the bottomland transects, where TC was 11 times higher in low impact sites than that in high impact sites.
- *Depth (thickness) of the A horizon - indicator of soil disturbance resulting from loss of topsoil (erosion) or mixing of A and E horizons.*
 - A-horizon depths drop when going to a higher disturbance category: bottomland sand-loam, Low to Medium; upland clay, Medium to High; upland sand, Low to Medium to High.
- *Microbial biomass (as C) - indicator of the size of the labile (readily bioavailable) soil C pool.*
 - Military disturbance has a significant effect on soil parameters related to soil organic matter dynamics, evidenced by decrease in MBC, TC, and labile carbon with increasing disturbance level. The result was that MBC contributed more to the total SOC pool in disturbed sites than in low impact sites; further resulting in a microbial biomass that was more efficient in converting a higher portion of C into MBC under disturbance.
- *Beta-glucosidase activity - indicator of the amount of bioavailable soil C.*
 - β -glucosidase did distinguish the three levels of impact in bottomland transects, perhaps indicating a higher ratio of available carbon to TC at intermediate levels of disturbance. Separation of moderate from low and severe impacts by β -glucosidase was less effective in upland soils.
- *Soil (microbial) respiration - indicator of the amount of bioavailable soil C.*
 - The response of CO₂ production between different levels of impact was due to differences in SOC quantity and quality. Average carbon dioxide flux was significantly higher ($P \leq 0.05$) in the low disturbance area and increasing disturbance significantly decreased CO₂ fluxes. Bare soil on the high impact transect exhibited the lowest CO₂ production, which is consistent with observations of Maljanen et al. (2001), who found the same trend when comparing bare soils with grassland and barley fields.
- *Ratios of microbial biomass to organic C and respiration to biomass - relative bioavailability of the soil organic C pool.*
 - The microbial biomass C within the pool of soil organic C, as indicated by MBC:TC ratio, was similar among vegetation types within a transect. A small amount of C was present within the microbial biomass, suggesting that the SOC availability was low. Seasonal variations in laboratory CO₂ efflux indicate changes in quantity and/or quality of SOC since it is run under controlled environmental conditions. The higher efflux in winter for upland sites was attributed to a higher concentration of labile SOC as indicated by K₂SO₄ extractable carbon. This form of extractable SOC is a potential sensitive indicator of labile SOC changes.
- *Relative bioavailability of soil C was higher in disturbed areas due to depletion of older, more stable soil organic matter.*

- Military disturbance has a significant effect on soil parameters related to soil organic matter dynamics, evidenced by decrease in MBC, TC, and labile carbon with increasing disturbance level. The result was that MBC contributed more to the total SOC pool in disturbed sites than in low impact sites; further resulting in a microbial biomass that was more efficient in converting a higher portion of C into MBC under disturbance.
- *Near Infrared Reflectance Spectroscopy (NIRS) for soil analysis is rapid, low-cost technique for determination of several individual soil biogeochemical properties and direct evaluation of derived soil quality metrics or indices.*
 - Reflectance measurements and 20 soil biogeochemical variables measured on over 550 soil samples were used to develop a robust PLS model for independently predicting TC, TN, and TP of new observations based on the reflectance measurements. The results presented indicate that near-infrared spectroscopy coupled with partial least squares can be a useful and inexpensive alternative to expensive and time consuming lab analyses.

Vegetation

Vegetative indicators that most accurately reflected the impacts of military training were:

- *Percent cover of herbaceous vegetation (ground cover, and litter cover), or in cases of more severe impacts, canopy cover.*
 - Herbaceous species composition and cover varied more with stand age than understory woody species.
 - Woody plants did not differentiate well among the disturbance levels; however, there was a trend of decreased overstory canopy cover with increased disturbance. Herbaceous vegetation composition on severely-disturbed sites segregated from low and medium disturbances but no segregation was found between the two lower levels of disturbance. Chronic, landscape-scale disturbances have resulted in a very resilient flora. Coverage of bare ground and plant litter may best serve as indicators of disturbance.
- *Plant species present only in severely disturbed sites identify the highest degree of disturbance.*
 - Relative cover of *Rubus* sp. and *Rhus copallina* may be an important indicator of a shift from moderate to severe conditions. These two species are prolific seed producers, enhancing their ability to colonize disturbed sites, and they appear to withstand physical disturbance once established. Those herbaceous species most closely associated with severely disturbed sites were: *Digitaria ciliaris*, *Diodia teres*, *Stylosanthes biflora*, Grass 4, *Aristida purpurescens*, *Opuntia humifusa*, *Haplopappus dirasicatus*, and *Paspalum notatum*. Solid stands of *Paspalum notatum*, an exotic species of grass, occurred on sites that had been totally denuded in the past, and probably was planted to reduce erosion.
- *Plant species indicating various stages of recovery from severe disturbance were identified that may be useful in tracking the progress of restoration efforts in highly-impacted areas.*
 - Species richness did not differ among age classes for either woody or herbaceous species, while species distribution and abundance did. *Bulbostylis barbata* and *Pityopsis* spp were identified as indicators of younger sites. *Andropogon* spp., *Dichanthelium* spp., and *Aristida* spp. have all been found to be more abundant soon after a disturbance, followed by a slow decrease in

frequency and abundance over. *Schizachyrium scoparium* and *Andropogon ternarius* were associated with 30-80 yr sites. *Schizachyrium scoparium* is considered a late successional plant throughout its range. While they occurred in all age classes, both increased with recovery time and had higher frequency and cover values on the oldest sites.

Indicators related to vegetation community composition in moderately or less impacted sites are often confounded by residual effects of prior soil disturbance related to agricultural land uses. Plant species potentially sensitive to low to moderate levels of disturbance probably have been extirpated from the sites due to historic levels of chronic disturbances. Indicator species to assess ecological condition may require an evaluation of “natural” or reference conditions prior to their use.

Hydrologic

Hydrologic indicators are of significant value for analysis of disturbance or recovery on a watershed scale.

- *Stream TOC and TKN concentration decreased with increasing soil and vegetation disturbance (proportion of bare ground) in the watershed, reflecting depletion of soil organic matter and detritus in uplands and reduced leaching in soils due to short-circuited flow paths (gulleys) from uplands to streams.*
 - Watersheds with more roads, e.g., Randall and Oswichee, have relatively high pH, conductivity, and Cl compared to the watersheds with fewer roads. Watersheds with a small portion of military land, e.g., Bonham-1, Sally, and Little Pine Knot, have relatively high TOC concentrations. In contrast, watersheds characterized by higher road densities, e.g., Bonham and Bonham-2, had low TP concentrations. Higher disturbance index, similar to the road density, showed lower TKN and TOC concentrations in the streams. Mixed vegetation, road length, percent of bare land, DIN, and number of roads crossing streams were able to capture most of the variability in water quality parameters.*
- *Analysis of hydrographs clearly reflect hydrologic imbalances resulting from soil and vegetation disturbance in uplands.*
 - In support of the finding that uplands in non-impacted areas do not contribute to the stream hydrograph, the contributing areas calculated by the stream hydrograph volumes and depth of rainfall events is less than the riparian/wetland area, suggesting that no area outside of the wetland/riparian area contribute to the stream hydrographs. In training areas, the Ksat is sufficiently low that overland flow could occur. Time of concentration for a 10cm/hr storm event was about 10 minutes. It is apparent that overland flow has gouged out deep gulleys and transported sediment from the hilltops. The

* Bhat, S., J.M. Jacobs, K. Hatfield, and J. Prenger. 2006. Ecological Indicators in Forested Watersheds: Relationships between Watershed Characteristics and Stream Water Quality in Fort Benning, GA. 6(2) 458-466.

flow processes in these areas are observed to be different than those in less-impacted watersheds. Overland flow is conceived to usher water toward roads that channel the water directly to streams, thus by-passing or short-circuiting the natural watershed flow paths.* Watershed physical characteristics scaled to correct for watershed area and slope may be used to characterize scaled physical characteristics of the watershed. Increasing disturbance index and military land are responsible for decreasing the scaled time to peak, response time, lag-to-peak, and time base of storm hydrographs. In addition to the disturbances noted above, increasing the road density within a watershed impacts increased the peak discharge across the landscape†.

- *Soil physical parameters (bulk density, porosity, texture, grain-size distribution, and saturated hydraulic conductivity) are potentially useful at small spatial scale.*
 - Smaller scaling factors imply smaller mean pore sizes of the training soils compared to the non-training soils. The higher soil bulk density values and lower infiltration rates of the training versus non-training areas are indications of the loss of organic matter combined with compaction from repeated tank track. The mean steady-state infiltration rate of the training sites (12.0 cm/hr) is less than half that of the non-training sites (26.8 cm/hr), but it is still greater than the maximum 100-yr, 24-hr rainfall intensity of 10 cm/yr.

General Conclusions

4. Approximately 2-15% of throughfall shows up as stream flow. Median value is approximately 6%. Time to peak discharge is approximately 3 hours.
5. Storm intensities are usually $<K_{sat}$ at most places, except severely disturbed areas.
6. Soil cover plays an important role in determining the potential runoff and may be more important than K_{sat} of surface soil.
7. Biogeochemical cycling in soils and vegetation are influenced by soil-water content.
8. Soil organic matter and several biogeochemical properties associated with C cycling are important biogeochemical indicators.
9. Spectral analysis shows excellent promise to determine soil nutrient status.
10. Understory vegetation species composition correlates with disturbance. Clear indicators generally observed only at heavily impacted sites.

* Perkins, D. 2003. Spatial and Temporal Characterization of Soil Hydraulic Properties and Soil-Water Storage Dynamics in Forested Watersheds. MS. Thesis, Purdue University.

† Bhat, S., J.M. Jacobs and K. Hatfield. Ecological Indicators in Forested Watersheds in Fort Benning, GA: Relationships between Land Use and Storm Flow Characteristics, Eos Trans. AGU, April 27, 2004, Joint Assembly Suppl., Abstract H41C-01, 2004.

11. Nutrient and sediment loads in “low” and “medium” impact sites are not too large. Sediment may be the most important water quality attribute for “severe” impact sites.
12. Water quality measurements revealed low levels of most nutrients.
13. Decreased canopy cover in wetlands and hardwood communities of impacted areas increase the nutrient load to streams.
14. Riparian zones play an important role in determining water quality.

Multivariate Analysis, Principal Component Analysis, and Canonical Correspondence Analysis yielded combinations of factors that are useful in identifying impacts.

Products

Publications associated with this research team are included in Appendix A.

5 Development of Ecological Indicator Guilds for Land Management — 1114B

2004 Annual Report
January 27, 2005

PI: Anthony Krzysik

Collaborators: H.E. Balbach, U.S. Army ERDC-CERL; J.J. Duda and J.M. Emlen, USGS Western Fisheries Research Laboratory; D.C. Freeman, Wayne State University; J.H. Graham, Berry College; D.A. Kovacic, University of Illinois-Urbana; J.C. Zak, Texas Tech University

Project Rationale and Objective

Military land-use must be efficiently and cost-effectively monitored to assess conditions and trends in natural resources relevant to training/testing sustainability, ecosystem maintenance, and the timing and success of restoration efforts. **Ecological Indicators** represent important land management tools for tracking ecological changes and providing early-warning detection of threshold impacts to prevent irreversible environmental damage. The objective of this research is to develop Ecological Indicators based on ecosystem relevance, multi-scale performance, and stress-response criteria, for the purpose of monitoring ecological changes directly relevant to biological viability, long-term productivity, and ecological sustainability of military training and testing lands.

Summary

The two major work efforts during 2004 were the preparation of manuscripts and presentations (see Professional Society Presentations in 2004, page 82, and Chapter 9, page 111). Three manuscripts were published, one was accepted, two are currently in review, and ten are currently in active preparation. An oral presentation was made at the annual Ecological Society of America meeting, and two posters were presented at professional meetings. A Draft Technical Report was written on SCI development. A standardized and weighed composite SCI was developed from eight Ecological Indicators. The analytical 40-site SCI scores faithfully represented the subjectively derived 10-class disturbance gradient in the complex physiography of the Fall-Line Sandhills. Ranked SCI scores from 40 diverse upland sites dis-

played a sigmoid logistic decay function, suggesting threshold effects at both the lowest and highest extremes of the broad landscape disturbance gradient. Research is continuing to refine the SCI, particularly in its application of contrasting simple and complex habitat structure in a landscape disturbance gradient.

Ant community composition and evenness (equitability) were good indicators of characterizing a landscape disturbance gradient in the Fall-Line Sandhills. Species richness of ants, however, is not useful, because it peaks with intermediate disturbance. Grasshoppers and katydids (only minor differences in community composition), and spiders (too diverse and taxonomically demanding) did not prove as useful or practical for Ecological Indicators.

Soil Mineralization Potential (nitrogen dynamics) appears to be an important and practical Ecological Indicator. After soil samples were incubated, ammonium (NH_4) concentration characterized Low disturbance sites, while nitrate (NO_3) characterized High disturbance sites.

Three microbial metrics were employed to assess and monitor habitat disturbance gradients: Microbial Biomass Carbon estimates in the top 10 cm of soil, substrate-use diversity by fungi and substrate-use diversity by bacteria. The fungi and bacteria communities across the disturbance gradient differed in their use of specific guilds of carbon substrates, and these were strongly dependent on environmental conditions of temperature, moisture, and nitrogen availability. Research and analyses are continuing to unravel these complex interdependent processes and to integrate this effort with nutrient leakage and nitrogen dynamics.

Detrended Fluctuation Analysis (DFA) to assess spatial organization in species dispersion patterns was conducted along a three-level disturbance gradient (Phase I). Although DFA was useful in a variety of other land-impact studies, it was not successful at identifying or characterizing plant community disturbance by military training activities.

Development of a Site Comparison (Condition) Index (SCI)

Background

There is widespread and growing interest in developing terrestrial metrics or indices that assess landscape condition and are capable of monitoring long-term ecological changes.* Terrestrial applications have proven difficult, and lag far behind the over two decade old stream-based IBI (Index of Biological Integrity) developed by Karr and colleagues.†

Interest was shown by DoD land management personnel to develop a standardized approach to objectively compare landscapes and quantify “habitat disturbance,” while minimizing subjective judgments and bias among field investigators. For example, sites called “Low,” “Medium,” and “High” disturbance may appear visually similar (Figure 5-1). Southeast upland forests were the initial test-bed for developing an SCI. The SCI was based on the data obtained to develop Ecological Indicators to assist land managers in assessing and monitoring forest condition, ecosystem processes, and associated ecological changes. Additionally, researchers engaged in SEMP-SERDP projects at Fort Benning suggested habitat parameters that they felt were ecologically important to assess landscape condition and disturbance.

* Andreassen, J.K., R.V. O'Neill, R. Noss, and N.C. Slosser. 2001. Considerations for the development of a terrestrial index of ecological integrity. *Ecological Indicators* 1:21-35.

Belnap, J. 1998. Choosing indicators of natural resource condition: A case study in Arches National Park, Utah, USA. *Environmental Management* 22:635-642.

Niemi, G.J., and M.E. McDonald. 2004. Application of ecological indicators. *Annual Review of Ecology, Evolution, and Systematics*. 35:89-111.

† Karr, J.R., and E.W. Chu. 1999. *Restoring Life in Running Waters: Better Biological Monitoring*. Island Press, Washington DC. 206pp.

Site Selection Phase I

Disjunct Landscape Disturbance Gradient

3 sites selected in each disturbance class

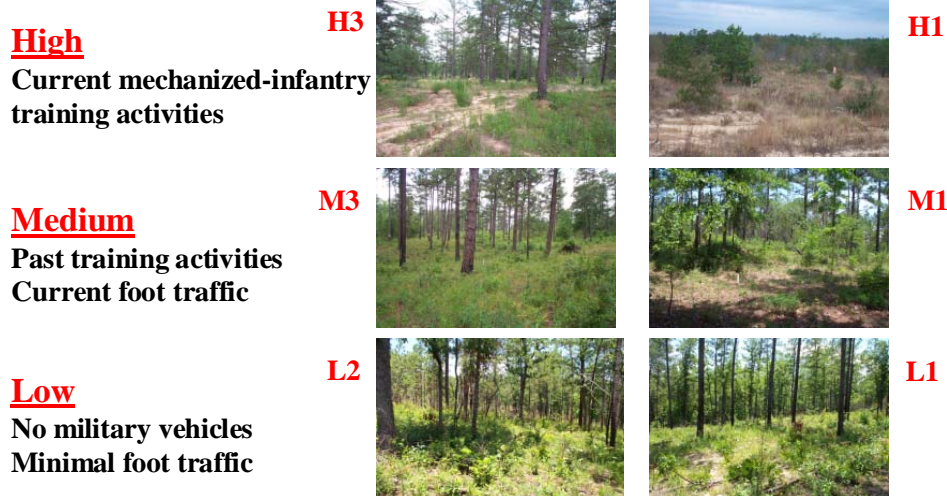


Figure 5-1. Phase I research High, Medium, and Low disturbance classes with two sites shown in each disturbance class. The other three sites are not shown.

Methods

The research was conducted at Fort Benning in west-central Georgia. This is the U.S. Army's primary infantry training facility, and also hosts a mechanized infantry brigade. The installation lies in the Fall-Line Sandhills, an ecologically complex transition zone between the rolling hills of the Piedmont and the broad Coastal Plain of the southeast, and includes the introgression of Loamy Hills from Alabama.

Nine sites were selected in **Phase I** research: three each in High, Medium, and Low disturbance classes based on current and past U.S. Army mechanized infantry training land-use (Figure 5-1). The objective of this research phase was to identify Ecological Indicators that modeled this disjunct disturbance gradient.

Phase II: Ecological Indicators identified in Phase I were evaluated at 40 sites that were selected to represent the widest range of landscape disturbance and upland vegetation communities present throughout Fort Benning. These 40 sites were classified into 10 landscape disturbance classes, based on the visual assessment of military training damage to vegetation and soils. Relatively pristine sites were classified as Disturbance Class 1 (DC1), and correspondingly, the most severely degraded sites were classified as DC10. The classification was conducted before any field data were collected by a researcher (Dr. Anthony J. Krzysik) with over 20 years of field experience with military training habitat disturbance.

Statistical Design

A critical element in the approach was an unusual attention to analytical and statistical rigor. Statistical rigor was particularly stressed in three areas:

1. unbiased systematic-random sampling designs,
2. the minimization of Type I error, and
3. analyses with high statistical power. Analyses with high statistical power minimize Type II error, but require high sample sizes.

Initial statistical comparisons of soil and vegetation metrics among disturbance classes were assessed with Tamhane's T2 multiple comparison test. This test is not only very conservative (minimizes Type I error), but also is the recommended procedure when variances are heterogeneous, the typical situation with environmental and habitat data.* The final selection of habitat parameters for the composite SCI was determined by linear regression of each individual habitat metric with disturbance class as the dependent variable. Only habitat metrics that had $P < 0.001$ were incorporated into the composite SCI (Table 5-1). Each selected variable was then standardized by giving the specific variable a score of 100 at the site where this variable had its highest value, and then proportionately adjusting the values of that variable at each of the remaining 39 sites.

Three statistical metrics were used to derive standardized weighed coefficients:

1. F-values from the individual simple linear regressions,
2. t-values from a linear multiple regression, and
3. Spearman's rho nonparametric correlations.

Multiple regression only selects variables that add statistical relevance, because variables that add no unique information to the regression (i.e., exhibit high multicollinearity) are excluded from the final multiple regression equation. A standardized composite SCI was derived for each of these methods by deriving proportional weighing coefficients based on the respective F-values, t-values, and nonparametric correlations, and the final SCI was calculated as the average of these three. All analyses were conducted with SPSS.†

* Tamhane, A.C. 1979. A comparison of procedures for multiple comparisons of means with unequal variances. *Journal of the American Statistical Association*, 74:471-480.

† SPSS. 2003. SPSS software, version 12.0.1. SPSS, Inc., Chicago, IL.

Selection of Ecological Indicators for the SCI

Table 5-1 presents 12 important Ecological Indicators identified by our team in Phase I and further validated in Phase II, and the 8 habitat metrics suggested by SEMP researchers. The eight indicators selected for the SCI are in red, based on $P < 0.001$.

Soil A-horizon depth and soil compaction were identified in Phase I by discriminant analysis as variables possessing the highest power to discriminate among the three disturbance classes (Figure 5-2). Litter cover was selected from 10 groundcover metrics, also using discriminant analysis (Figure 5-3). DF1 had a correlation of 0.95 with “bare ground,” and also with litter cover, which is defined as “100 minus bare ground”. The separate measures are thus redundant, and litter cover was used as the measure. Although canopy cover, basal area, and tree density are typically highly correlated; they each represent different components of vegetation structure and forest development. Therefore, all three were included in SCI development.

Table 5-1. Selection of Ecological Indicators for the SCI.

The eight proposed metrics by SEMP researchers are in the first column. The team’s identified 12 Ecological Indicators are in the second column. The eight indicators selected for the SCI are in red, based on $P < 0.001$. *Litter Cover was selected by Discriminant Analysis (see Figure 5-3).

Research Metric Proposed	Ecological Indicator Tested	Statistical Significance (P) Based on Simple Linear Regression
Soil A-Horizon Depth	A-Horizon Depth	<0.001
Soil Compaction	Soil Compaction	<0.001
Soil-Sediment Carbon	Soil Organic Microbial Biomass Carbon	<0.001 0.006
Soil-Sediment Nitrogen	Ammonium (NH ₄) Nitrate (NO ₃)	0.66 0.038
Surface Cover (satellite)	NDVI	<0.001
Canopy Cover	Canopy Cover	<0.001
Vegetation Structure	Basal Area	<0.001
	Tree Density	<0.001
	Litter Cover (100-Bare Ground)*	<0.001
	Total Ground Cover	0.21
Species Composition	Not Evaluated (taxonomic expertise required by land manager)	-----

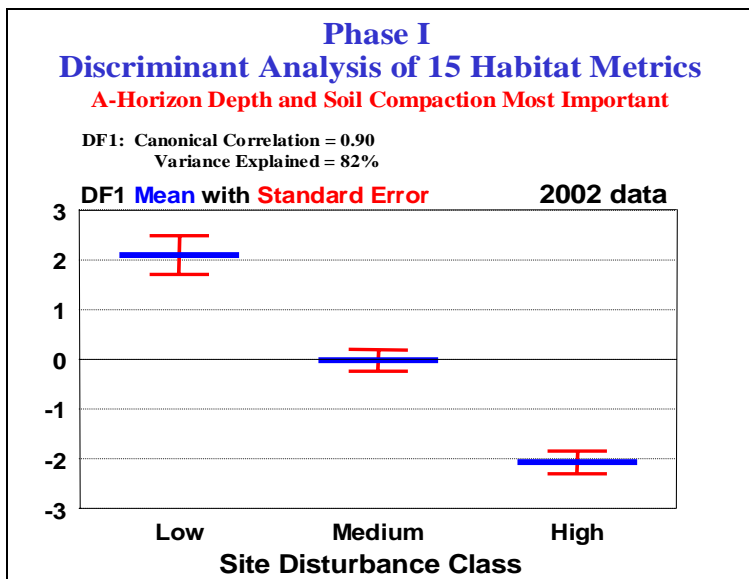


Figure 5-2. Discriminant analysis of 15 habitat variables from Phase I. Discriminant Function 1 was primarily loaded by A-horizon depth and soil compaction.

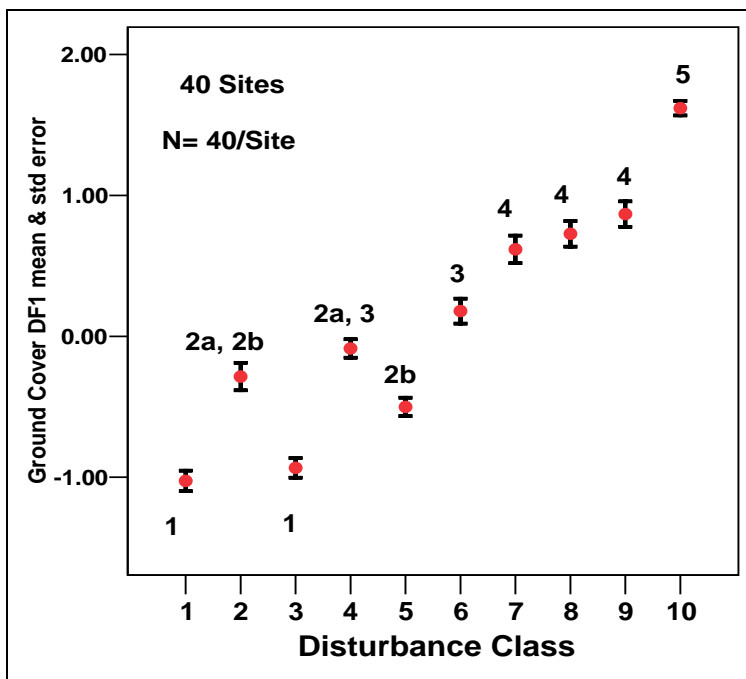


Figure 5-3. Ground cover DF1 scores (mean and standard error) at the 40 sites based on disturbance class. Numbers represent statistically similar disturbance classes.

The Normalized Difference Vegetation Index (NDVI) is often used to assess and monitor landscape condition because it measures net primary productivity, and cor-

relates strongly with LAI (leaf area index), FPAR (fraction of absorbed photosynthetically active radiation), field-measured net primary production, measures of chlorophyll, and albedo.* Figure 5-4 shows NDVI values for the 40 sites relative to the 10 disturbance classes. NDVI was only able to distinguish between the most pristine and highly disturbed sites, although there was a clear trend in the decline of NDVI between DC6 to DC10.

A-horizon depth characterizes the disturbance gradient extremely well (Figure 5-5). There was a smooth, linear, monotonic decrease of the A-horizon with increasing disturbance. DC3 was the single exception, but it was not significantly different from either DC4 or DC2. The consistent pattern in this figure was analytically verified by the pairing of adjacent Disturbance Classes, resulting in five statistically significant groups based on A-horizon depth.

The pattern of soil compaction for the 40 sites (Figure 5-6) was similar to A-horizon depth, but there were seven statistically significant disturbance classes, and the most pristine and most disturbed sites were dramatically separated from the other classes. Statistical groupings differed from that displayed by A-horizon depth. DC2 contains the site with the highest clay content (13.6%). Soils with higher clay content typically demonstrate higher levels of soil compaction.

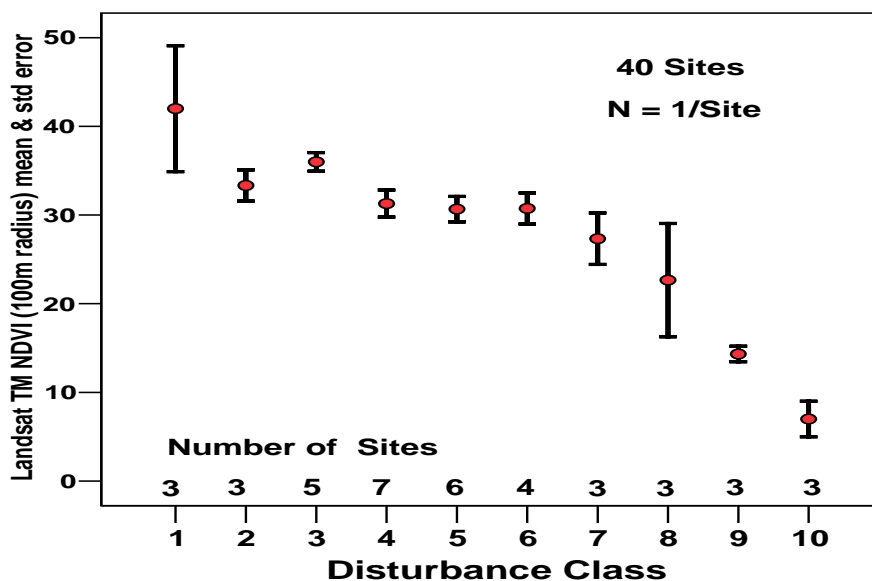


Figure 5-4. NDVI (mean and standard error) at the 40 sites based on disturbance class.

* Franklin, S.E. 2001. Remote Sensing for Sustainable Forest Management. Lewis Pub., Boca Raton, FL. 407pp.

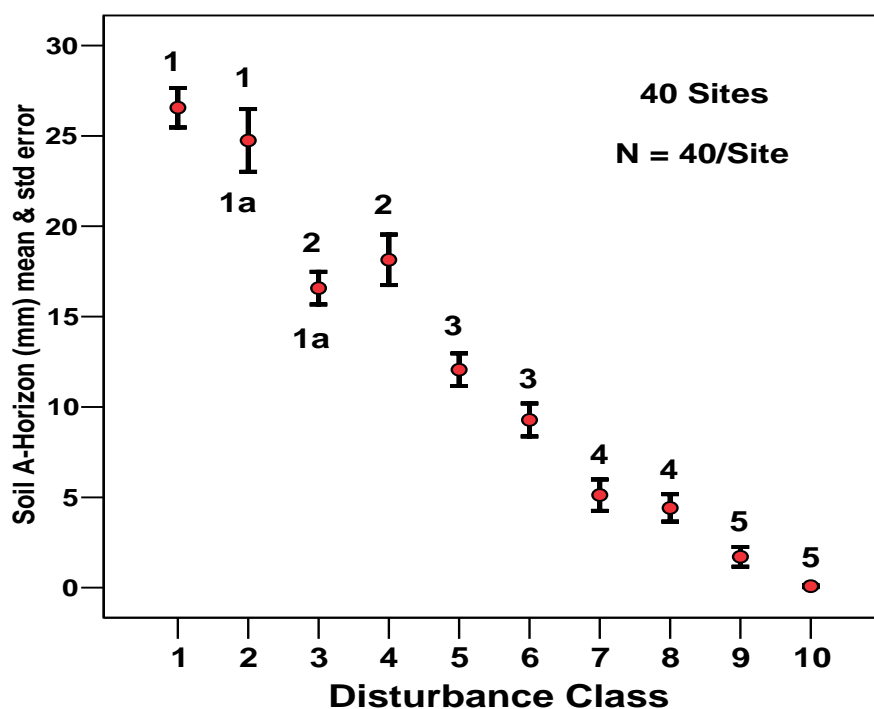


Figure 5-5. Soil A-horizon depth (mean and standard error) at the 40 sites based on disturbance class.

See Figure 5-4 for number of sites in each disturbance class. Numbers represent statistically similar disturbance classes.

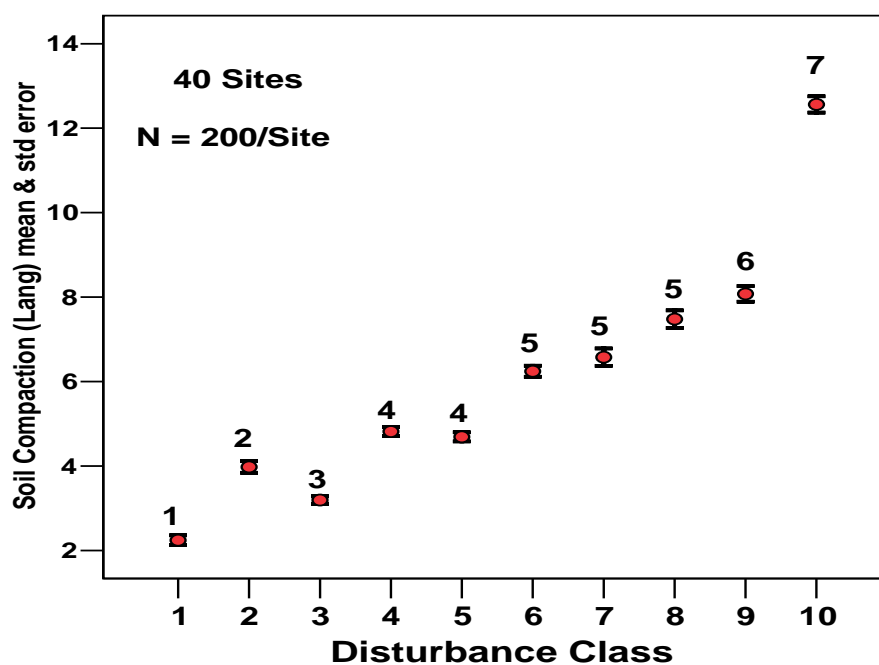


Figure 5-6. Soil compaction (mean and standard error) at the 40 sites based on disturbance class.

See Figure 5-4 for number of sites in each disturbance class. Numbers represent statistically similar disturbance classes.

Site Comparison Index

Figure 5-7 presents the SCI scores (means with standard errors) for the 10 disturbance classes. Note that SCI scores declined smoothly and linearly as habitat disturbance increased. The SCI, based on 8 statistically significant and ecologically important soil and vegetation parameters, modeled the 10-class disturbance gradient extremely well. The relatively pristine sites and very degraded sites clearly separated themselves from the other sites. There were two minor exceptions: DC2 and DC4 had slightly lower SCI scores than expected. These results are robust and gratifying for several important reasons. Virtually identical patterns were obtained with the three “intermediate SCIs” that were averaged to produce the “final SCI.” Additionally, the final weighed composite SCI was similar in pattern to A-horizon depth (Figure 5-5) and soil compaction (Figure 5-6). These two indicators were identified in Phase 1 research as being the most important habitat variables defining the 9-site/3-class land-use disturbance gradient. The robustness in analyses can be attributed to the high multicollinearity inherent in habitat metrics that attempt to quantify a disturbance gradient. Scores from the analytical unbiased SCI reproduced almost perfectly the disturbance ranking assigned by a very experienced observer, thus non-subjective uniformity of ranking was achieved.

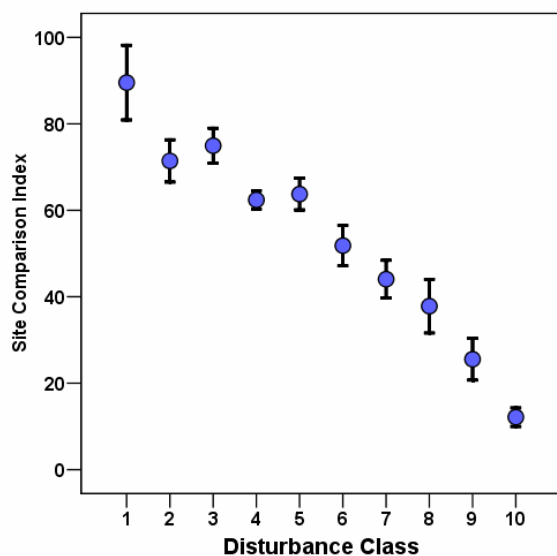


Figure 5-7. Site Comparison Index for the 10 disturbance classes. The standardized SCI was based on eight Ecological Indicator variables weighed by statistical criteria. Note that the ordinate is a relative scale. See Figure 5-4 for number of sites in each disturbance class.

The 40 sites were ranked by their respective SCI scores (Figure 5-8). The histogram of SCI scores for the SCI-ranked 40 sites revealed a *sigmoid logistic decay function*, analytically demonstrating that relatively few sites were either very high quality or very severely degraded, and suggesting a “threshold effect” of rapidly de-

clining SCI values as disturbance increases from “pristine sites” or as it approaches severely degraded sites. Discrepancies between SCI and Disturbance Class rankings revealed interesting ecosystem patterns that are currently under investigation.

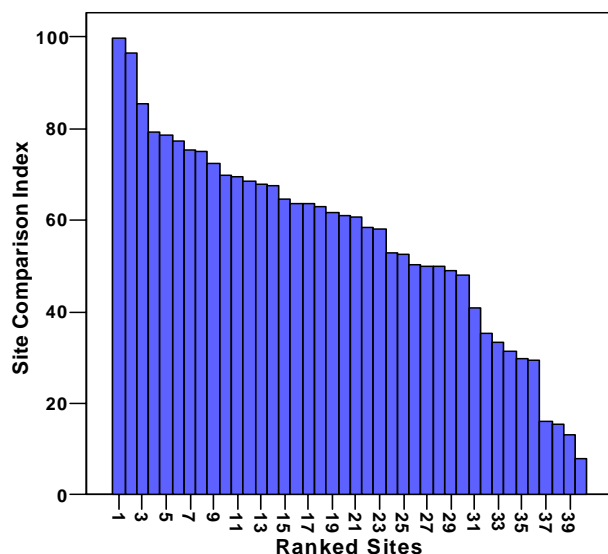


Figure 5-8. Site Comparison Index scores for the 40 sites ranked by their respective SCIs.

The two highest ranked sites based on the SCI were mesic forests with complex and predominantly deciduous vegetation, and they were also in DC1 (Figure 5-9 and Figure 5-10). A pristine xeric site also in DC1 was ranked relatively low by the SCI (9th), presumably because the site had sparser vegetation development with less structure than the mesic sites (Figure 5-11). The site with the lowest SCI score (40th) was in the central portion of a major training area (Delta), possessed a great deal of bare ground, and was classified as a DC10 (Figure 5-12).



Figure 5-9. Highest SCI rank (B2), mesic southern red oak – mixed pine forest, DC1, 71% deciduous.



Figure 5-10. Second highest SCI rank (E5), mesic oak – hickory forest, DC1, 97.5% deciduous.



Figure 5-11. A xeric but pristine site (K13), scrub oak – longleaf pine savanna, DC1, but ranked 9th by SCI.



Figure 5-12. Lowest SCI rank (D15-1), Delta Training Area, mixed pine – hardwoods, DC10.

The largest discrepancy between SCI and disturbance class ranking was a relatively pristine (DC2) maturing Longleaf Pine Forest with simple vegetation structure (i.e., physiognomy) in rocky rolling hills with unusual wind-eroded sandstone outcrops (Figure 5-13). This site was ranked 19th by the SCI.



Figure 5-13. Relatively pristine longleaf pine forest (F4) in rocky rolling hills with simple vegetation structure, DC2, ranked 19th by SCI.

These preliminary results in developing a Site Comparison Index from a wide variety of upland vegetation communities in the complex physiographic setting at Fort Benning are indeed encouraging. Nevertheless the data were collected at a single location in the Fall-Line Sandhills. Additional data is required from a larger geographic area and an even greater variety of vegetation communities and soil types (especially clayey), both in the Southeast and in other regions of the United States.

Invertebrate Communities

Ant Diversity

Species richness by itself was a poor indicator of disturbance — it was greatest in sites that were moderately disturbed.* The most diverse site for ants was D15-4 with 25 species of ants. This site was relatively disturbed (DC7, SCI rank 29th) and the habitat was a mosaic of light and shade (Figure 5-14). In contrast, a relatively pristine mesic oak-hickory forest (E5, DC1, SCI rank 2nd, Figure 5-10) had only five species of ants, while a heavily disturbed training area (D15-1, DC10, SCI rank 40th, Figure 5-12) had four species. Evenness (equitability), on the other hand, was inversely correlated with other measures of disturbance, and showed no intermediate-disturbance peak (Figure 5-15). Ant communities in undisturbed deciduous forest sites had low species richness and low abundance of ants, but evenness was high. Ant communities in highly disturbed training areas had few species, high abundance, and low evenness.



Figure 5-14. Site D15-4, DC7, ranked 29th by SCI. This site had the highest species richness of ants.

* Graham, J.H., H.H. Hughie, S. Jones, K. Wrinn, A.J. Krzysik, J.J. Duda, D.C. Freeman, J.M. Emlen, J.C. Zak, D.A. Kovacic, C. Chamberlin-Graham, and H.E. Balbach. 2004. Habitat disturbance and the diversity and abundance of ants (Formicidae) in the Southeastern Fall-Line Sandhills. *Journal of Insect Science* 4:30, 15pp. (online at <http://insectscience.org/4.30/>)

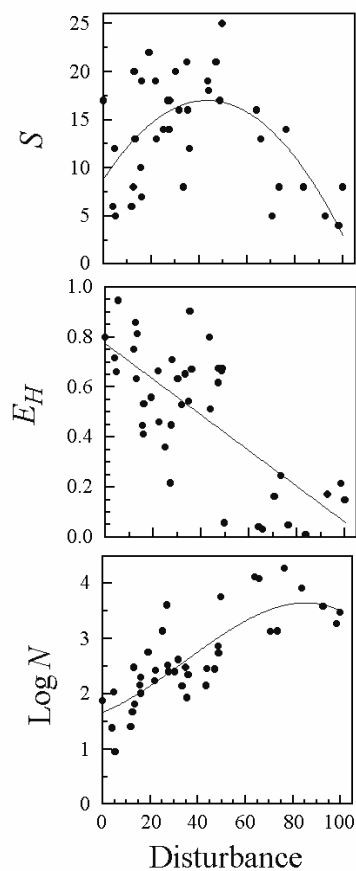


Figure 5-15. Species Richness (S), Evenness (Equitability) (EH), and Abundance (log N) of ants on the 40 sites disturbance gradient.

Intermediate Disturbance

Ant communities in the Fall-Line Sandhills exhibited a hump-backed species diversity curve, associated with intermediate disturbance (Figure 5-15). The high species richness at intermediate disturbance is associated with greater within-site spatial heterogeneity, but not with NDVI (a correlate of net primary productivity). Nevertheless, species richness was related to available primary production (product of NDVI and number of days in the year that the maximum soil temperature exceeded 25 °C).

Ant Community Composition

Ant community composition was a good indicator of disturbance. Three species of ants were particularly associated with disturbed sites: *Pheidole bicarinata*, *Dorymyrmex smithi*, and *Pogonomyrmex badius* (Figure 5-16).

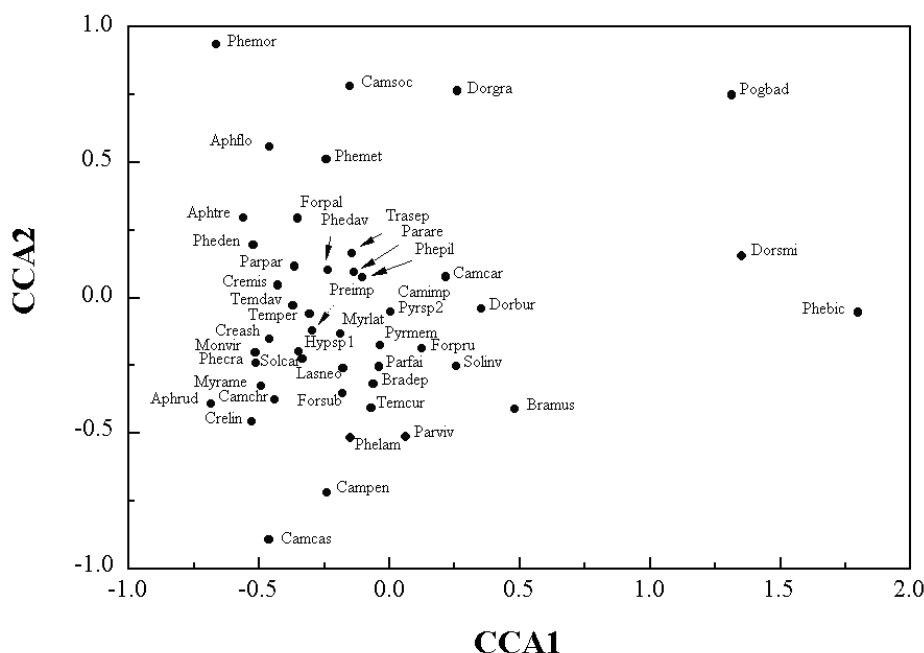


Figure 5-16. Canonical correspondence analysis of Fort Benning ant communities.

Spiders (Araneae)

Spiders are the dominant predators of the arthropod community. Unfortunately, they are far too diverse and taxonomically difficult to be useful for routine studies. At the time this research switched over from spiders to ants, the researchers had tabulated more than 200 morphospecies. Preliminary analysis, however, indicated substantial differences in community composition of spiders among disturbance regimes (Figure 5-17).

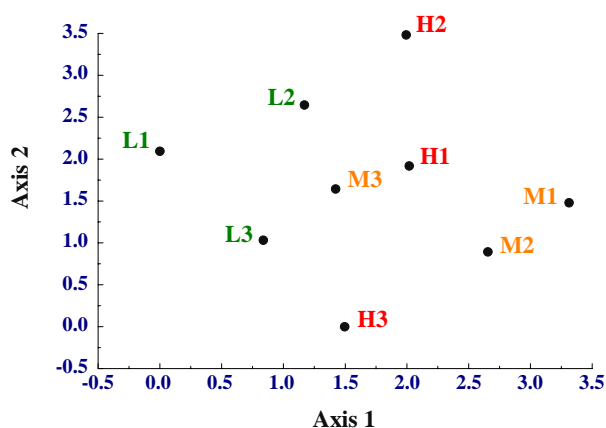


Figure 5-17. Detrended correspondence analysis of spider communities at Fort Benning. Low disturbance sites are in dark green, Medium sites in orange, and High disturbance sites in red.

Grasshoppers and Katyids (Orthoptera)

Grasshoppers and katydids are the most conspicuous herbivores in the arthropod community. In grasslands, they are typically the dominant herbivores.* Taxonomically, they are easier to identify than either the ants or spiders. Moreover, low species richness (13 species of grasshoppers and 3 species of katydids) makes them easy to work with.

We identified and counted 621 grasshoppers (Acrididae) and katydids (Tettigoniidae), sampled in 3 consecutive years (2000-2002). Although there were no differences in either species richness or relative density of grasshoppers and katydids among the disturbance regimes, there were minor differences in community composition (Figure 5-18). In particular, *Trimerotropis maritima* was restricted to highly disturbed sites. This species is found primarily in coastal strand habitats, and other sandy habitats.† *Orphulella pelidna*, *Schistocerca americana*, and *Conocephalus fasciatus* were also more common in disturbed areas.

The condition (maximum width standardized by total length) of the two most widely distributed species, *Pardalophora phoenicoptera* and *Melanoplus femurrubrum*, was less in the highly disturbed areas. After correcting for total length, both *Pardalophora phoenicoptera* and *Melanoplus femurrubrum* had a smaller maximum width in the highly disturbed areas (Analysis of Covariance: $P < 0.05$).

There was no difference in fluctuating asymmetry (a measure of Developmental Instability) of two leg traits and four wing traits among *P. phoenicoptera* and *M. femurrubrum* the three disturbance classes.

* Risser, P.G., E.C. Birney, H.D. Blocker, S.W. May, W.J. Parton, and J.A. Weins. 1981. The true prairie ecosystem. Hutchinson Ross, Stroudsburg, PA. 557pp.

† Friauf, J.J. 1953. An ecological study of the Dermaptera and Orthoptera of the Welaka area in northern Florida. Ecological Monographs 23:79-126.

Squitier, J.M., and J.L. Capinera. 2002. Habitat associations of Florida grasshoppers (Orthoptera: Acrididae). Florida Entomologist 85:235-244.

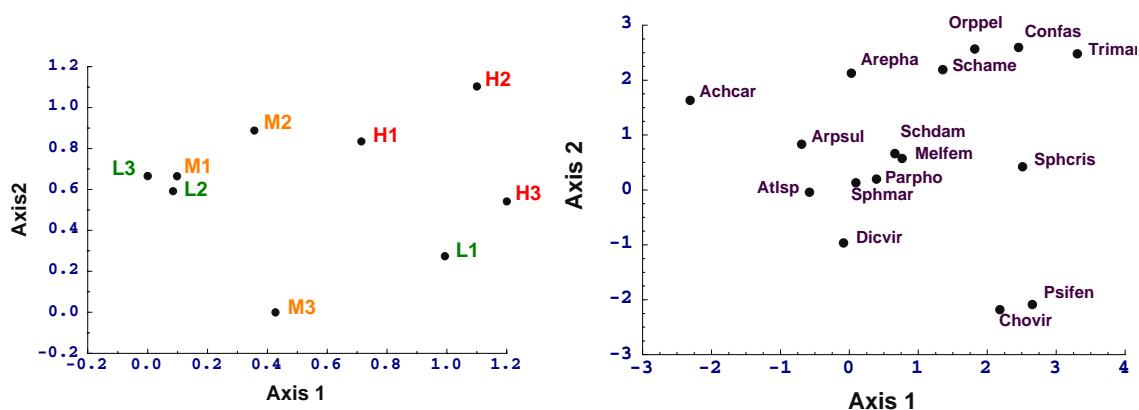


Figure 5-18. Detrended correspondence analysis of grasshopper and katydid Fort Benning communities.

Low disturbance sites are in dark green, Medium sites in orange, and High disturbance sites in red.

Soil Mineralization Potential as an Ecological Indicator

Soil Mineralization Potential appears to be an important Ecological Indicator. Note that ammonium (NH_4) characterizes Low disturbance sites, while nitrate (NO_3) characterizes High disturbance sites (Figure 5-19). Medium sites were intermediate and variable in their ammonium/nitrate ratio. This Ecological Indicator suggested that the M2 site was the most disturbed Medium site; this was substantiated by other indicator systems.

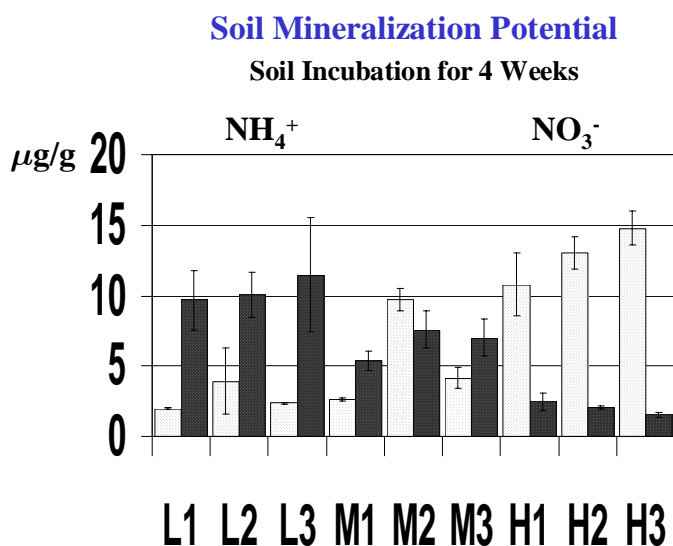


Figure 5-19. Soil Mineralization Potential for soil samples incubated in the laboratory for four weeks.

Note that ammonium (NH_4^+) is more concentrated in the Low disturbance sites, while nitrate (NO_3^-) is more concentrated in the High disturbance sites.

Microbial Ecology

Microbial Dynamics

The approach used to understand microbial responses to military training disturbance is designed to relate microbial dynamics to ecosystem-level processes that are not readily apparent or easily measured. Three metrics were selected: (1) Microbial Biomass Carbon estimates in the top 10 cm of soil from research sites, (2) the functional diversity of soil fungi using carbon utilization on a wide diversity of substrate resources in quantitative laboratory assessments, and (3) the comparative carbon utilization by soil bacteria. In addition, individual site and seasonal responses were examined at the level of substrate guilds for both fungi and bacteria. Substrate guilds were based on: simple carbohydrates, complex carbohydrates, carboxylic acids, amino acids, amines/amides, nucleotides, and polymers. While differences among sites may not be detected using total numbers of substrates (substrate richness), site differences may occur at the level of specific substrate guild responses. Differences among disturbance levels, seasons, and years were then examined across the substrate guilds, using temperature, moisture, and nitrogen as covariates.

Fungal Functional Diversity

Substrate guild activity for fungi varied across the disturbance sites in response to season and year. Seasonal differences in substrate guild usage within sites reflected soil fungal responses to local moisture inputs. Differences in soil fungal activity within disturbance classes across years also reflected yearly differences in precipitation inputs.

Phase I Sites: The High disturbance sites exhibited the greatest differences in usage of amines/amides, amino acids, carboxylic acids, complex carbohydrates, and simple carbohydrates between seasons and across years in comparison with the Medium and Low disturbance sites. The Low disturbance sites differed in simple carbohydrate usage across years with consistent usage of the other substrate guilds. At the Medium disturbance sites, fungal usage of complex carbohydrates and amino acids differed across season and year. These patterns of carbon usage reflect the physiological status of the fungi within the soils of the sites as they process soil carbon and react to nitrogen availability patterns in response to disturbance impacts.

Phase II Sites: Preliminary analysis indicates that substrate guild use differences among the 40 sites can be attributed to differences in nitrogen demand (amines/amides, and amino acids) and the availability of simple carbohydrates.

Bacterial Functional Diversity

Phase I Sites: Simple carbohydrate usage by soil bacteria varied the most when compared with the other substrate guilds across years. Simple carbohydrate usage by soil bacteria was the lowest in May 2000. Simple carbohydrate use did not vary substantially among disturbance classes. The lack of differences in simple carbohydrate use among the disturbance classes reflects the importance of simple carbohydrates to the activity of the soil bacteria. For complex carbohydrates, the lowest usage of this class of carbon compounds occurred in the Medium and High disturbance sites. Complex carbohydrate usage by soil bacteria for the Low disturbance sites was fairly consistent across season and year, suggesting that the variability expressed in the Medium and High disturbance sites does reflect the impacts of soil disturbance by military training activities and subsequent alteration of soil properties and vegetation structure.

The greatest seasonal variation in the use of nitrogen-containing carbon compounds by soil bacteria (amino acids and amines/amides) were found in the High and Medium disturbed sites. These data again suggest that abiotic stress from seasonal drought and high soil temperatures during the summer in the more exposed High disturbance sites restricts the ability of the soil bacteria to process these compounds. When conditions are optimum, there is little difference among disturbance classes for the use of these compounds. In the Low disturbance sites, amino acid, amine, and amide use by soil bacteria is fairly consistent from season to season and across years.

Phase II Sites: The on-going analysis of the bacterial substrate usage data for the 40 sites has revealed that differences among these various locations occurred primarily in the numbers of nitrogen-containing carbon compounds (amino acids, amines/amides) that can be used for growth, and the rates at which these compounds are metabolized. While the sites differ in the rates at which soil bacteria at these locations use simple and complex carbohydrates and carboxylic acids in response to site-specific conditions, the differences in the numbers of carbon compounds they can use (substrate richness) may not be a good indicator of disturbance.

Microbial Activity in Response to Soil Temperature

Phase I Sites: We continue to evaluate the impacts of soil temperatures during the summer as a key regulator of microbial activity at the High disturbance sites. We collected additional soil and air temperature data from our original locations in September 2004 from the 12 stations that remained functional. These data sets are crucial to understanding the seasonal patterns of soil temperatures that occur over time within the three disturbance classes. As discussed above, the substrate guild

data suggests that abiotic stress, such as soil temperatures, is a key regulator of bacteria activity and dynamics in the High disturbance sites when compared with bacterial dynamics associated with the Medium and Low disturbance classes.

Detrended Fluctuation Analysis to Assess Spatial Organization in Species Dispersion Patterns

Are lands at Fort Benning under stress from military activities? One difficulty in answering this question is the hypothesis that ecological systems alter their structure and dynamics under stress in such manner as to alleviate that stress. That being the case, it is critical that we define our reasons for asking the question in the first place. If an ecosystem has already responded to stress by changing into a new self-perpetuating dynamic, it is of course useful to have quantitative descriptors to define both the original and the new states. In terrestrial ecosystems, soil characteristics (depth, profile, compaction, and nutrient concentrations) fall primarily into this category, as do most aspects of species composition and richness. On the other hand, if the goal is to avoid or possibly mitigate ecosystem change, we are interested, in early warning metrics that indicate threshold approach or changing conditions. This is particularly in regards to those ecosystem characteristics that society deems important or are irreversible. Jorgensen and others have proposed thermodynamic measures that they believe indicate disruptions to ecosystem dynamics.* Specifically, changes in exergy (i.e., the quality of available and useable energy) may reflect changes in a system's operating efficiency. By analogy to organisms, a stressed system's heat radiation should rise relative to its energy intake under stress.† These sorts of measures may vary over time with an ecosystem's dynamic, but should remain within predictable limits established from examining undisturbed systems. Acquiring the requisite data to apply these ecosystem energetic metrics is costly and the theory under-developed. Chen and Bak (1989) offer an alternative, proposing for systems in general, "energy is dissipated following a power-

* Jorgensen, S.E., B.C. Patten, and M. Straskraba. 1999. Ecosystems emerging: 3, Openness. *Ecological Modeling* 117:41-64.

Toussaint, O., and E.D. Schneider. 1998. The thermodynamics and evolution of complexity in biological systems. *Comparative Biochemistry and Physiology, Part A* 120:3-9.

Kay, J.J. 2000. Ecosystems as self-organizing holarchic open systems: Narratives and the second law of thermodynamics, Pages 135-159 in *Handbook of Ecosystem Theories and Management*. S.E. Jorgensen and F. Muller, eds. Lewis Pub., New York, NY, 584pp.

† Emlen, J.M., D.C. Freeman, A. Mills, and J.H. Graham. 1998. How organisms do the right thing: The attractor hypothesis. *CHAOS* 83:717-726.

law distribution with many small and a few large events, producing a fractal spatial structure that is effectively a snapshot of the temporal dynamic”.^{*} Accordingly, we turn from measures involving ecosystem dynamics, to examining the structure those dynamics determine.

Alados et al. (2003) recently used Detrended Fluctuation Analysis (DFA) to measure changes in community structural complexity in the face of ecosystem stress.[†] DFA provides a measure of spatial autocorrelation, and thus, the structural organization reflecting dynamic ecosystem properties. In areas experiencing habitat disturbance, we should expect organization to be disrupted and correspondingly exhibiting less autocorrelation. Here, we measured spatial autocorrelation in the woody understory of a mixed pine-hardwoods ecosystem subjected to disturbance from military training activities and prescribed fires. Our objective was to evaluate DFA as a measure of ecosystem disruption, and therefore, a potential Ecological Indicator of impending ecosystem changes.

DFA is based on the concept of a random walk, which describes a purely random sequence of “steps.” There will be a net positive or negative average trend in score over these steps, and a variance (and standard deviation) in cumulative score about that trend. If the steps are random, that is, if the direction of one step is wholly independent of the direction of preceding steps, then this standard deviation rises with the square root of L , the length of the segment over which it is measured:

$$S_L \propto L^{0.5}, \text{ or}$$

$$\ln(S_L) = c + (0.5)\ln(L)$$

where c is a constant. On the other hand, structural order implies something other than randomness. Thus, the more general expression is

$$S_L \propto L^{\alpha}, \text{ or}$$

$$\ln(S_L) = c + \alpha\ln(L)$$

^{*} Chen, K., and P. Bak. 1989. Is the universe operating at a self-organized critical state? *Physics Letters A*. 140:299-302.

[†] Alados, C.L., Y. Pueyo, M.L. Giner, T. Navarro, J. Escos, F. Barroso, B. Cabezudo, and J.M. Emlen. 2003. Quantitative characterization of the regressive ecological succession by fractal analysis of plant spatial patterns. *Ecological Modeling* 163:1-17.

Peng, C.K., S.V. Buldyrev, S. Havlin, M. Simons, H.E. Stanley, and A.L. Goldberger. 1994. Mosaic organization of DNA nucleotides. *Physics Review E*, 49:1685-1689.

If the pattern is non-random, α is something other than 0.5.

We presume that interactions, both with other ramets of the target species and with other species, lead to the development of a dispersion pattern that is nonrandom, and that is characteristic of the community in which the target species finds itself. But if these normal patterns of interaction are disrupted due to military training disturbance, there should follow a breakdown in that dispersion pattern, and accordingly, degeneration toward randomness. Areas with greater disturbance should exhibit alpha values closer to 0.5 than less disturbed areas.

To avoid biases due to sparse information, we looked only at species and sites for which there were at least 10 intercepts along a 300-m transect, a total intercept length of at least 3 m (an arbitrary choice of 1% of the total transect). All corresponding species and sites exhibited an adjusted R^2 for the log-log regression of at least 0.90.

Our sites were selected, *a priori*, to represent a range of military training disturbance. The sites were subjected to controlled burning by forestry personnel according to a schedule independent of our experiments. Thus the design was both incomplete and unbalanced regarding fire history. A two-way ANOVA, nevertheless, can be used to test for alpha differences between sites experiencing different military disturbance levels, and among sites burned in the current year or not. This approach, however, requires the lumping of alpha values across species, a practice of questionable validity. Therefore, we also used a nonparametric approach, looking at the number of instances in which the alpha values for a given species, in a given year, in a given fire status, were on average higher or lower across the disturbance gradient.

All alpha values exceeded 0.5 regardless of the level of military training disturbance or fire, indicating that the structure of these communities is nonrandom. Looking at the number of times alphas, for a given species, year, and fire history, were higher (vs. lower) in disturbed vs. undisturbed site classes, we found no apparent trend. Using the same approach to compare alphas between years markedly differing in precipitation, we also found no trend. Finally, under the presumption that alpha values are invariant among species, unlikely but perhaps worth considering as a possibility, we used two-way ANOVA with disturbance as a fixed effect and fire history as a random factor to look for differences in alpha values. Again, there was no difference for either effect ($F_{90,1} = 0.528$, $p = 0.600$ for fire history; $F_{90,1} = 0.267$, $p = 0.696$ for land disturbance; $F_{90,1} = 0.350$, $p = .555$ interaction).

There are at least two reasons why these results might be so weak. First, because of the spatial patchiness of military training disturbance, it was impossible to con-

struct transects of adequate (statistical) length, and the transects extended across more than one level of disturbance. Second, the woody ground cover, which was the subsystem examined, can be expected to react to disturbance much more quickly than the higher overlying canopy. Thus, whatever stresses originally had been imposed by military activities might have dissipated quickly by community reorganization; that is, the disruption of autocorrelation patterns might have been ameliorated over time by changes in species composition, population densities, and the physical alterations thereby affected. In other words, the disturbance regime may have become the norm to a newly self-organized system. Had we been able to utilize much longer transects and had we looked at canopy vegetation, we may have found more dramatic results.

Holling introduced the ideas of resistance and resilience to describe the behavior of dynamic ecosystem attractors in the face of disturbance.* If the environmental milieu changes (e.g., via anthropogenic disturbance) the system's trajectory may deviate from its characteristic pattern. As long as the change falls below some threshold, the system will resist such deviation. Resilience is the capacity of the system to return to the characteristic trajectory once the stress is removed. Yet, should the change be great enough or, perhaps last long enough, the system shifts into a new attractor that defines a new dynamic-structural pattern appropriate to the altered milieu. If disturbance follows a persistent pattern with intervals much shorter than the system's recovery time, it can be considered a part of the environmental milieu.† Under such circumstances, the system may become unstable and shift into a new trajectory.‡ In such cases, the resulting community is referred to as a disclimax.

Both our statistical analysis and the analysis of soil characteristics demonstrated that the sites experiencing different levels of military disturbance are quite distinct. Each site probably represents a distinct disclimax, or has been displaced to a differ-

* Holling, C.S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4:1-23.

Holling, C.S. 1992. Cross-scale morphology, geometry, and dynamics of ecosystems. *Ecological Monographs* 62:447-502.

† Sousa, W.P. 1984. The role of disturbance in natural communities. *Annual Review of Ecology and Systematics* 15:353-391.

Wiegand, T., K.A. Moloney, and S.J. Milton. 1998. Population dynamics, disturbance, and pattern evolution: Identifying the fundamental scales of organization in a model ecosystem. *American Naturalist* 152:321-337.

Peterson, G.D. 2002. Contagious disturbance, ecological memory, and the emergence of landscape pattern. *Ecosystems* 5:329-338.

‡ Turner, M.G., W.H. Romme, R.H. Gardner, R.V. O'Neill, and T.K. Kratz. 1993. A revised concept of landscape equilibrium: Disturbance and stability on scaled landscapes. *Landscape Ecology* 8:213-227.

ent successional stage or path. Because alpha values show no significant differences among them, the former is suggested. Displacement from a characteristic trajectory reflects disrupted organization, and therefore differential drops in alpha towards 0.5. The lack of evidence for drops in alpha values between unburned and just burned sites suggests that fire must also be an integral component of the “normal environment”. This is expected as prescribed burning is carried out on a fairly consistent schedule.

Products

Publications associated with this research team are included in Appendix A.

Professional Society Presentations in 2004

A great deal of effort and time was spent in presentation preparations in 2004, and these results are summarized below.

Presentations and Posters

Ecological indicators for assessing and monitoring ecosystem conditions along a broad disturbance gradient in the Fall-Line Sandhills upland forests of Georgia. Krzysik, A.J., D.A. Kovacic, M.P. Wallace, J.H. Graham, J.C. Zak, J.J. Duda, J.M. Emlen, D.C. Freeman, C.C. Graham, H.E. Balbach, and R.C. Lozar. Oral Presentation: Ecological Society of America Annual Meeting, 4 August 2004, Portland, OR.

Site Comparison Index: Can We Create a Meaningful Index Value to Rank Site Condition? Balbach, H.E., and A.J. Krzysik. Poster: American Agronomy Society, 1-5 November 2004, Seattle, WA.

Development of Ecological Indicator Guilds: A Site Comparison Index for the Southeast Fall-Line Sandhills. Krzysik, A.J., H.E. Balbach, D.A. Kovacic, J.C. Zak, J.H. Graham, M.P. Wallace, J.J. Duda, D.C. Freeman, and J.M. Emlen. Poster: SERDP Partners in Technology Symposium, 30 November – 2 December 2004, Washington, DC.

6 Indicators of Ecological Change — CS

1114C

Final Report

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PI: Virginia Dale

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Background

Some of the finest surviving natural habitat in the United States is on military reservations where land has been protected from development. However, military training activities often necessitate ecological disturbance to that habitat. Fort Benning, Georgia, contains active infantry training grounds and more than 65,000 ha of soils capable of supporting longleaf pine (*Pinus palustris*) forest, a greatly reduced forest type in the North America. Because longleaf pine forests are the pri-

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mary habitat for the federally-endangered red-cockaded woodpecker (*Picoides borealis*), land managers at this installation have a dual charge both to maintain conditions for mechanized training activities and to conserve the integrity of this landscape.

Characterizing how resource use and management activities affect ecological conditions is necessary to document and understand ecological changes. Resource managers on military installations have the delicate task of balancing the need to train soldiers effectively with the need to maintain ecological integrity. Ecological indicators can play an important role in the management process by providing feedback on the impacts that training has on environmental characteristics.

The challenge in using ecological indicators is in determining which of the numerous measures of ecological systems best characterize the entire system but are simple enough to be effectively monitored and modeled. Ecological indicators quantify the magnitude of stress, degree of exposure to stress, or degree of ecological response to the exposure and are intended to offer a simple and efficient method to examine ecological composition, structure, and function of whole systems. The use of ecological indicators as a monitoring device relies on the assumption that the presence or absence of, and fluctuations in, these indicators reflect changes taking place at various levels in the ecological hierarchy.

Although few scientists deny the benefits that indicators provide to research and management efforts, three concerns jeopardize the use of ecological indicators as a management tool.

- **Management and monitoring programs often depend on a small number of indicators and, as a consequence, fail to consider the full complexity of the ecological system.** By selecting only one or a few indicators, the focus of the ecological management program becomes narrow, and an oversimplified understanding of the spatial and temporal interactions is created. This simplification often leads to poorly informed management decisions. Indicators should be selected from multiple levels in the ecological hierarchy in order to effectively monitor the multiple levels of complexity within an ecological system.
- **Choice of ecological indicators is often confounded by management programs that have vague management goals and objectives.** Unclear or ambivalent goals and objectives can lead to “the wrong variables being measured in the wrong place at the wrong time with poor precision or

reliability”^{*} Primary goals and objectives should be determined early in the process in order to focus management. Ecological indicators can then be selected from system characteristics that most closely relate to those management concerns.

- **Management and monitoring programs often lack scientific rigor because of their failure to use a defined protocol for identifying ecological indicators.** Lack of a procedure for selecting ecological indicators makes it difficult to validate the information provided by those indicators. Until a standard method is established for selecting and using indicators, interpretation of their change remains speculative. The creation and use of a standard procedure for the selection of ecological indicators allow repeatability, avoid bias, and impose discipline upon the selection process, ensuring that the selection of ecological indicators encompasses management concerns.

Development of a procedure for ecological indicator selection that is based on a hierarchical framework and grounded in clear management goals will address concerns associated with the subjective and disorganized methods often used. We present such an approach for identifying ecological indicators. The ultimate goal is to establish the use of ecological indicators as a means for including ecological objectives and concerns in management decisions.

The approach is applied to DoD lands in the United States where military land contributes significantly to habitat conservation. The DoD manages more than 10 million ha representing more than 450 installations nationally. Although this area is much less land than the area managed by the Department of the Interior (180 million ha) or the United States Forest Service (USFS, 77 million ha), greater species diversity per unit area exists within DoD lands than within lands of any other federal ownership (except Department of Energy lands). In addition, DoD lands contain more endangered species per unit area than any other federal land management agency, and individual installations often contain more land than most national parks or wildlife refuges. While a portion of all military installations is highly disturbed, most land within military bases is designated as training areas or buffer zones and, therefore, remains in a relatively natural state, providing numerous habitats and a haven for associated species. These facts coupled with the DoD's commitment to ecosystem management and conservation provide an outstanding

^{*} Noss, R. & Cooperrider, A. (1994) *Saving Nature's Legacy: Protecting and Restoring Biodiversity* (Washington DC, Island Press).

opportunity for establishing sustainable management practices that ensure the future of these habitat and species resources. Although its mission is military training and testing, the DoD recognizes the relationship between its military mission and the natural resources upon which that mission depends, and, therefore, the benefits of creating and implementing long-term ecosystem-management plans.*

This research explored the use of ecological indicators as a land management tool, focusing on the development of a procedure for selecting and monitoring ecological indicators. In response to the limitations that currently hamper the effectiveness of ecological indicators as a management device, we considered a hierarchical approach to land management and the role indicators can play in providing the monitoring information required by ecosystem management. This summary discusses criteria and presents the suite of indicators that we considered for military land use at the landscape, watershed, and plot level. The development and implementation of land-management strategies for military land not only provide valuable tools for the continued mission of the DoD, but also suggest how ecological indicators can be used for ecosystem management of other multiple-use lands.

Criteria for Selecting Ecological Indicators

Selection of effective indicators is key to the overall success of any monitoring program. In general, ecological indicators need to capture the complexities of the ecosystem yet remain simple enough to be easily and routinely monitored. In order to define ecological indicators, however, it is first necessary to set forth criteria used to select potential ecological indicators. Building upon discussions in the scientific literature and discussions with the other SEMP research teams and the resource managers at Fort Benning, we suggest that ecological indicators should meet the following criteria:

- **Be easily measured.** The indicator should be straightforward and relatively inexpensive to measure. The metric needs to be easy to understand, simple to apply, and provide information to managers and policymakers that is relevant, scientifically sound, easily documented, and cost-effective.
- **Be sensitive to stresses on the system.** The ideal ecological indicator is responsive to stresses placed on the system by human actions while also having limited and documented sensitivity to natural variation. While some

* Goodman, S. W., Implementation of Ecosystem Management in the DoD, Memorandum, DUSD(ES)/EQ-CO, 08 AUG 1994,

indicators may respond to all dramatic changes in the system, the most useful indicator is one that displays high sensitivity to a particular and, perhaps, subtle stress, thereby serving as an early indicator of reduced system integrity.

- **Respond to stress in a predictable manner.** The indicator response should be unambiguous and predictable even if the indicator responds to the stress by a gradual change. Ideally, there is some threshold response level at which the observable response occurs before the level of concern.
- **Be anticipatory.** The indicator should signify an impending change in key characteristics of the ecological system. Change in the indicator should be measurable before substantial change in ecological system integrity occurs.
- **Predict changes that can be averted by management actions.** The value of the indicator depends on its relationship to possible changes in management actions.
- **Are integrative.** The full suite of indicators provides a measure of coverage of the key gradients across the ecological systems (e.g., gradients across soils, vegetation types, temperature, space, time, etc.). The full suite of indicators for a site should integrate across key environmental gradients. For example, no single indicator is applicable across all spatial scales of concern. The ability of the suite of indicators to embody the diversity in soils, topography, disturbance regimes, and other environmental gradients at a site should be considered.
- **Have a known response to disturbances, anthropogenic stresses, and changes over time.** The indicator should have a well documented reaction to both natural disturbance and to anthropogenic stresses in the system.
- **Have low variability in response.** Indicators that have a small range in response to particular stresses allow for changes in the response value to be better distinguished from background variability.

Landscape Indicators

This research examined landscape indicators that signal ecological change in both intensely used and lightly used lands at Fort Benning, Georgia. Changes in patterns of land cover through time affect the ecological system by altering the proportion and distribution of habitats for species that these cover types support. Landscape patterns, therefore, are important indicators of land-use impacts, past and present, upon the landscape. This analysis of landscape pattern began with a landscape characterization based on witness tree data from 1827 and the 1830s and remotely sensed data from 1974, 1983, 1991, and 1999. The data from the early 1800s, although coarse, were useful in characterizing the historical range of variability in ecological conditions for the area. The steps for the analysis involved cre-

ating a land-cover database and a time series of landcover maps, computation of landscape metrics, and evaluation of changes in those metrics over time as evidenced in the land-cover maps. We focused on five cover types (bare/developed land, deciduous forest, mixed forest, pine forest, and nonforest vegetated land), for they reveal information important to resources management at Fort Benning. An examination of landcover class and landscape metrics, computed from the maps, indicated that a suite of metrics adequately describes the changing landscape at Fort Benning. The most appropriate metrics were percent cover, total edge (km), number of patches, descriptors of patch area, nearest neighbor distance, the mean perimeter-to-area ratio, shape range, and clumpiness. Identification of such ecological indicators is an important component of building an effective environmental monitoring system.

Watershed Indicators

To evaluate watershed scale indicators of disturbance we studied twelve 2nd- and 3rd-order streams in the eastern part of the Fort Benning Military Installation (FBMI) that drained watersheds with a wide range of disturbance levels. We quantified watershed disturbance as the sum of the proportion of bare ground on slopes greater than 3 percent and unpaved road cover within each watershed. Study streams drained watersheds ranging in disturbance from about 2 to 14 percent. We then compared a variety of stream physical, chemical, and biological characteristics across this disturbance gradient to evaluate their usefulness as disturbance indicators.

We found that a number of stream characteristics were good indicators of watershed-scale disturbance at FBMI. Stream channel organic variables (i.e., amount of benthic particulate organic matter [BPOM] and coarse woody debris [CWD]) were highly related to watershed disturbance as was the degree of hydrologic flashiness (quantified by 4-hour storm flow recession constants) and bed stability. Among the stream chemistry variables, the concentrations of total and inorganic suspended sediments during baseflow and storm periods were excellent indicators of disturbance, typically increasing with increasing disturbance levels. In addition, baseflow concentrations of dissolved organic carbon and soluble reactive phosphorus were good disturbance indicators, declining with increasing disturbance levels. Among biological variables, stream benthic macroinvertebrates also were good indicators of watershed-scale disturbance. Traditional measures such as community richness (e.g., number of Ephemeroptera, Plecoptera, and Trichoptera [EPT] taxa and richness of Chironomidae) negatively corresponded with watershed disturbance; however, except for chironomid richness, all measures showed high variation among seasons and annually. A multimetric index previously designed for Georgia streams

(Georgia Stream Condition Index [GASCI]) consistently indicated watershed disturbance and also showed low seasonal and inter-annual variation. Low diversity of fish precluded use of traditional measures (i.e., richness, diversity), however the proportional abundance of the two dominant populations (*P. euryzonus* and *S. thoreauianus*) were strongly but oppositely associated with disturbance, with *P. euryzonus* and *S. thoreauianus* being negatively and positively related to disturbance, respectively. Finally, historical land use explained more variation in contemporary bed stability and longer-lived, low-turnover taxa than contemporary land use, suggesting a “legacy” effect on these stream measures. Prior to identification and use of potential indicators, managers at FBMI should acknowledge historical land use and the possible presence of legacy effects on aquatic physicochemical and biotic conditions.

Plot-level Indicators

Vegetation Indicators

Environmental indicators for longleaf pine (*Pinus palustris*) ecosystems need to include some measure of understory vegetation because of its responsiveness to disturbance and management practices. To examine the characteristics of understory species that distinguish between disturbances induced by military traffic, we randomly established transects in four training intensity categories (reference = no military use, light = foot traffic only, moderate = marginal tracked vehicle use, and heavy = regular tracked vehicle use) and in an area that had been remediated following intense disturbance at Fort Benning. A total of 137 plant species occurred in these transects with the highest diversity (95 species) in light training areas and the lowest (16 species) in heavily disturbed plots. Forty-seven species were observed in only one of the five disturbance categories. The variability in understory vegetation cover among disturbance types was trimodal ranging from less than 5 percent cover for heavily disturbed areas to 67 percent cover for reference, light, and remediated areas. High variability in species diversity and lack of distinctiveness of understory cover led us to consider Raunkiaer life form and plant families as indicators of military disturbance. Life form successfully distinguished between plots based on military disturbances. Species that are phanerophytes (trees and shrubs) were the most frequent life form encountered in sites that experienced light infantry training. Therophytes (annuals) were the least common life form in reference and light training areas. Chamaephytes (plants with their buds slightly above ground) were the least frequent life form in or moderate and remediation sites. Heavy training sites supported no chamaephytes or hemicryptophytes (plants with dormant buds at ground level). The heavy, moderate, remediated, and reference sites were all dominated by cryptophytes (plants with underground buds) possibly because of

their ability to withstand both military disturbance and ground fires (the natural disturbance of longleaf pine forests). Analysis of soils collected from each transect revealed that depth of the A layer of soil was significantly higher in reference and light training areas, which may explain the life form distributions. In addition, the diversity of plant families and, in particular, the presence of grasses and composites were indicative of training and remediation history. These results are supported by prior analysis of life form distribution subsequent to other disturbances and demonstrate the ability of life form and plant families to distinguish between military disturbances in longleaf pine forests.

We further investigated the hypothesis that effects of military activity on these forests may be quantified by grouping understory species into life-forms by experimentally manipulating a longleaf pine forest using a mechanized vehicle. In May 2003, a D7 bulldozer removed extant vegetation and surface soil organic matter along three treatment transects. Braun-Blanquet vegetation surveys were recorded in June and September 2003 and 2004. Repeated measures analysis of variance was used to compare the response of 30 plots within the treatment transects to 30 plots in adjacent control transects. Total understory cover in the treatment transects decreased substantially in June, but rebounded by September 2003. Phanerophytes (trees and shrubs) in the treatment plots maintained reduced cover throughout the growing season. These findings support the use of Raunkiaer functional types in indicating the response of longleaf pine forests to mechanized disturbance. This approach should lead to a readily accessible measure of disturbance that can be assessed throughout the installation by land managers.

Microbial Indicators

This research demonstrated that the soil microbial community of a longleaf pine ecosystem at Fort Benning also responds to military traffic disturbances. Using the soil microbial biomass and community composition as ecological indicators, reproducible changes showed that increasing traffic disturbance decreases the soil viable biomass, biomarkers for microeukaryotes, and Gram-negative bacteria, while increasing the proportions of aerobic Gram-positive bacterial and *actinomycete* biomarkers. Soil samples were obtained from four levels of military traffic (reference, light, moderate, and heavy) with an additional set of samples taken from previously damaged areas that were remediated via planting of trees and ground cover. Utilizing 17 phospholipid fatty acid (PLFA) variables that differed significantly with land usage, a linear discriminant analysis with cross-validation classified the four groups. Wilks' Lambda for the model was 0.032 ($P < 0.001$). Overall, the correct classification of profiles was 66 percent (compared to the chance that 25 percent would be correctly classified). Using this model, ten observations taken from the remediated transects were classified. One observation was classified as a reference, three

as light trafficked, and six as moderately trafficked. Non-linear Artificial Neural Network (ANN) discriminant analysis was performed using the biomass estimates and all of the 61 PLFA variables. The resulting optimal ANN included five hidden nodes and resulted in an r^2 of 0.97. The prediction rate of profiles for this model was again 66 percent, and the ten observations taken from the remediated transects were classified with four as reference (not impacted), two as moderate, and four as heavily trafficked. Although the ANN included more comprehensive data, it classified eight of the ten remediated transects at the usage extremes (reference or heavy traffic). Inspection of the novelty indexes from the prediction outputs showed that the input vectors from the remediated transects were very different from the data used to train the ANN. This difference suggests as a soil is remediated it does not escalate through states of succession in the same way as it descends following disturbance.

Considering Soil, Vegetation, and Microbial Indicators Together

Our results and those of Chuck Garten* (under another SEMP project) show that soil chemistry, soil microbes, and vegetation are all important indicators of ecological change. Accordingly, we questioned whether all of these indicators would be important if we combined these data into one analysis. Our hypothesis was that a suite of indicator types is necessary to explain ecological change. A discriminant function analysis was conducted to determine whether these ecological indicators could differentiate between different levels of military use. A combination of ten indicators explained 90 percent of the variation among plots from five different military-use levels. Results indicated that an appropriate suite of ecological indicators for military resource managers includes vegetation, microbial, and soil characteristics. This result is important for resource managers since many of the indicators are correlated, it implies that managers will have freedom to choose indicators that are relatively easy to measure, without sacrificing information.

Road and Vehicle Impacts at Different Scales at Fort Benning

Roads and vehicles change the environmental conditions in which they occur. One way to categorize these effects is by the spatial scale of the cause and the impacts.

* Garten, C.T., T.L. Ashwood, and V.H. Dale. 2003. "Effect of military training on indicators of soil quality at Fort Benning, Georgia." *Ecological Indicators* 3(3) 171-180.

Roads may be viewed from the perspective of road segments, the road network, or roads within land ownership or political boundaries such as counties. Our research examined the hypothesis that the observable impacts of roads on the environment depend on spatial resolution. To examine this hypothesis, the environmental impacts of vehicles and roads were considered at four scales in west central Georgia in and around Fort Benning: a second-order catchment, a third-order watershed, the entire military installation, and the five-county region including Fort Benning. Impacts from an experimental path made by a tracked vehicle were examined in the catchment. Land-cover changes discerned through remote sensing data over the past three decades were considered at the watershed and installation scales. A regional simulation model was used to project changes in land cover for the five-county region. Together these analyses provide a picture of the how environmental impacts of roads and vehicles can occur at different spatial scales. Following tracked vehicle impact with a D7 bulldozer, total vegetation cover responded quickly, but the plant species recovered differently. Soils were compacted in the top 10 cm and are likely to remain so for some time. Examining the watershed from 1974 to 1999 revealed that conversion from forest to nonforest was highest near unpaved roads and trails. At the installation scale, major roads as well as unpaved roads and trails were associated with most of the conversion from forest to nonforest. For the five-county region, most of the conversion from forest to nonforest is projected to be due to urban spread rather than direct road impacts (using a model developed for another SERDP project). The study illustrates the value of examining the effects of roads at several scales of resolution and shows that road impacts in west central Georgia are most important at local to subregional scales.

Technology Transfer

The objective of this study was to identify indicators that signal ecological change in intensely and lightly used ecological systems (all Fort Benning has had some anthropogenic changes) that could be used by the resource managers. Because the intent was that these indicators become a part of the ongoing monitoring system at the installation, the indicators were selected for their feasibility for the installation staff to measure and interpret. While the focus was on Fort Benning, the goal was to develop an approach to identify indicators that would be useful to a diversity of military installations and other land ownerships (in some cases the actual indicators may be adopted). The intent of this identification of indicators was to improve managers' ability to manage activities that are likely to be damaging and to prevent long-term, negative effects. Therefore, we examined a suite of variables needed to measure changes in ecological conditions. The results of the research were presented to the Fort Benning Resource managers in a half day workshop in February 2005.

Conclusions

Landscape Indicators

Data collected for disparate purposes can be used to help develop an understanding of landcover changes over time and are often necessary to further our knowledge of historic conditions on a given landscape. For the entire Fort Benning landscape, the values of landscape metrics for 1827 were very different from the values for recent decades. While the changes between 1827 and 1974 may be somewhat exaggerated due to data constraints, we can conclude that the nineteenth century landscape at Fort Benning was composed largely of uninterrupted pine forest with some deciduous forests found in riparian corridors and some open areas associated with Native American settlements. Land cover and land use in the 1970s were considerably different. Following decades of farming, military training activities had a pronounced effect upon the landscape. Heavy training activities resulted in areas of sparse land cover and bare ground. Interestingly, these areas have largely persisted on the landscape throughout the 1980s and 1990s. This result not only emphasizes the lasting footprint that military activities have on the landscape but also highlights the efforts made by management to confine heavy training exercises to certain sacrifice areas. Another interesting trend occurred in the 1990s. Pine forests have been on the rise as is reflected in both landscape composition and patch dynamics such as largest patch size, number of patches, and total edge. Management efforts at Fort Benning have focused upon managing for longleaf pine. These efforts appear to be decreasing hardwood invasion in favor of pine species in many areas on the installation.

Examining a suite of landscape metrics over time was useful for summarizing, describing, and assessing landcover change at Fort Benning. The FRAGSTATS and ATtILA programs were relatively simple to use and provided information pertinent to understanding and managing the land. Therefore, we encourage resource managers to use landscape metrics to analyze changes in patterns of land cover over time to examine how human activities have affected an area.

Furthermore, work has already begun on obtaining and classifying historical aerial photography from the 1940s and 1950s. The characterization of additional time periods between 1827 and 1974 will be extremely useful in bridging the gap in our understanding of the landscape dynamics between the nineteenth century landscape and the established military base of the 1970s.

Watershed Indicators

We found that a number of physical, hydrological, chemical, and biological characteristics of streams were good indicators of watershed-scale disturbance at FBMI. Stream channel organic variables (e.g., Benthic Particulate Organic Matter, (BPOM), and Coarse Woody Debris (CWD) were highly related to disturbance and thus were good indicators. Additionally, the degree of hydrologic flashiness (as quantified by 4-hour storm flow recession constants) and bed stability were good indicators of watershed-scale disturbance. Among the stream chemistry variables, the concentrations of total and inorganic suspended sediments during baseflow and storm periods were excellent indicators of disturbance, increasing with increasing disturbance levels. In addition, baseflow concentrations of DOC [Ed: dissolved organic carbon?] and SRP [Ed: standard reduction potential?] were good disturbance indicators, declining with increasing disturbance levels. The magnitude of increases in SRP and possibly NO_3^- concentrations during storms also appeared to be good disturbance indicators. Among the biological variables, stream benthic macroinvertebrates also served as good indicators of watershed-scale disturbance. Traditional measures such as richness measures (e.g., number of EPT taxa and richness of Chironomidae) negatively corresponded with watershed disturbance; however, except for chironomid richness, all measures showed high variation among seasons and annually. A multimetric index previously designed for Georgia streams (GASCI) consistently indicated watershed disturbance and exhibited low seasonal and annual variation. Low diversity of fish precluded use of traditional measures (i.e., richness, diversity), however the proportional abundance of the two dominant populations (*P. eurizonus* and *S. thoreauianus*) were strongly but oppositely associated with disturbance, with *P. eurizonus* and *S. thoreauianus* being negatively and positively related to disturbance, respectively. Finally historic land use explained more variation in contemporary bed stability and longer-lived, low-turnover taxa than contemporary land use, suggesting a legacy effect on these stream measures. Prior to identification and use of potential indicators, we recommend that FBMI land managers consider land use history and the potential for legacy effects on contemporary conditions in streams.

Plot-level Indicators

We hypothesized that understory diversity and cover sampled from an anthropogenic disturbance gradient within the longleaf pine forests would reveal significant compositional and structural differences that occurred as a result of military training intensity. The confirmation of life form distribution and plant family cover as distinguishing features suggests that monitoring programs for longleaf pine forests should include understory vegetation as an ecological indicator. These metrics can serve as surrogate measures of disturbance to the longleaf pine system. Both life

form distribution and plant family cover appear to be useful ways to group the large number of species which occur in the understory of these longleaf pine forests.

Indicators of disturbance that are used for resource management need to be easy to measure, sensitive to stresses, and predictable as to how they respond to stress. Selecting indicators for the understory of longleaf pine forests is complicated by the high species diversity. Field classification of understory plants according to life form and family is relative straightforward compared to species identification. Both of these attributes are relatively easy and time efficient to measure and interpret. Thus we recommend that the suite of indicators used for monitoring longleaf pine ecosystems include these metrics.

Another goal of this project was to explore the possibility of using the soil microbial community as an ecological indicator signaling the degree of environmental degradation along a disturbance gradient. The analysis based on the soil PLFA was successful, reflected above-ground changes, and provided an index of the degree of land disturbance (traffic) the soil received. Both linear discriminant and non-linear ANN analysis were able to adequately classify the degree of disturbance. However, there were drawbacks when the ANN and linear discriminant models were used to predict stages of soil recovery in remediated transects. The linear discriminant model was shown to be a fairly robust but perhaps coarse measure of remediative efforts, and the ANN was sufficiently sensitive to detect subtleties in recovery not detected with the linear discriminant analysis, but in current form could not be relied on to classify remediated samples. The inclusion of data reflecting remediation in these models could possibly make them capable of monitoring a more complete process of soil degradation and recovery. Soil microbial analysis provides indicators of ecological condition that respond in a short time to changes in land-use practices. Field collection requires minimal work, and samples can be shipped to commercial laboratories for analysis. Soil microbial condition is an important metric to gauge changing conditions on the land at Fort Benning.

Overall Summary

These studies support the hypothesis that a suite of metrics is useful for measuring changes in ecological conditions at Fort Benning. That suite should include landscape metrics of current and historical conditions, watershed indicators, and plot-level metrics (including both changes in vegetation and soil microbial biology). Together these indicators reveal information about changes at critical spatial and temporal points. For specific management questions, the resource managers are urged to select from the suite of indicators analyzed in this research as well as those

presented by other researchers for those indicators that best meet the criteria for the task.

Products

Publications associated with this research team are included in Appendix A.

Professional Society Presentations in 2004

Posters

Druckenbrod, D.L. and V.H. Dale. Effects of tracked-vehicle disturbance on longleaf pine understory vegetation through two growing seasons. SERDP/ESTCP - Annual Technical Symposium and Workshop. November - December 2004, Washington, DC.

Maloney, K. O., J. W. Feminella, P. J. Mulholland, and J. N. Houser. 2004. The influence of historic and contemporary land use on present-day streams: land use legacies and Fort Benning streams. Poster presentation at the 2004 Department of Defense Conservation Conference at Savannah, GA.

Maloney, K. O., A. Burnette, R.M. Mitchell, J.W. Feminella. 2004. Are fish assemblages influenced by military land use in small streams at Fort Benning, Georgia? Poster presentation presented at the American Society of Limnology and Oceanography (ASLO), Savannah, GA.

Presentations

Baskaran, L., V. Dale, M. Aldridge, M. Berry, W. Birkhead, M. Chang, R. Efroymsen, C. Garten, C. Stewart, Habitatat modeling within a Regional Simulation Model (RSim) environment, 4th Southern Forestry and Natural Resource Management GIS Conference, Athens, GA, Dec 16-17, 2004.

Druckenbrod, D.L. and V.H. Dale. Oral Presentation: Experimental response of understory plants to mechanized disturbance in longleaf pine forests at Fort Benning, GA. Ecology Society of America Annual Meeting. August 2004, Portland, Oregon.

Maloney K. O., and J. W. Feminella. 2004. Land use legacies at Fort Benning, Georgia, USA: are small streams influenced more by historic than contemporary land use? North American Benthological Society (NABS) meeting, Vancouver, BC, Canada.

Maloney, K. O. J.W. Feminella, P. J. Mulholland, and J. N. Houser. 2004. Land use legacies and small streams: the relationship between historic and contemporary land use patterns with present-day stream conditions 2004. Alabama Water Resources Conference, Orange Beach, Alabama.

Mulholland, P. J., Feminella, J. W., Lockaby, B. G., Houser, J. N., Maloney, K. O., Miller, S., Mitchell, R., and Roberts, B. J. Impacts of military training activities on riparian ecosystems at Fort Benning, Georgia. 2004 DoD Conservation Conference (August 22-24 in Savannah).

7 Thresholds of Disturbance: Land Management Effects on Vegetation and Nitrogen Dynamics — 1114E

Final Report

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Lead principal investigator: Dr. Beverly Collins; Associate investigator Dr. John Dilustro, Savannah River Ecology Laboratory

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Executive Summary

Land at Fort Benning is used for multiple purposes. Current land use for military training ranges from light disturbance by foot and occasional light vehicle traffic to heavy disturbance by repeated armored vehicle traffic. Upland mixed pine/hardwood forests are thinned and periodically burned to promote longleaf pine (*Pinus palustris*) savanna for the endangered red-cockaded woodpecker (*Picoides borealis*). These land uses occur over a heterogeneous environment. The installation's location in the Fall-Line Sandhills region is an ecotone between the Piedmont and

Coastal Plain provinces. Vegetation and soils are influenced by topography, drainage, periodic fires, and a long history of human use. Some combinations of land uses may not be sustainable over upland environments at Fort Benning. The ecosystem may lose nutrients or fail to regenerate desirable species. Objective 3 of FY2000 SON (CSSON-00-03) requested research to “determine whether there are thresholds in spatial extent, intensity or frequency above and/or below which the natural system cannot sustain identified ecological and/or land use disturbances.” The Savannah River Ecology Laboratory (SREL) conducted a field experiment to evaluate the ecological effects of military training and forest management for longleaf pine at Fort Benning, to determine if there are thresholds beyond which upland ecosystems cannot sustain the combined effects of these land uses.

This research was conducted from 2000 through 2004 in 32 upland forest stands at Fort Benning. We manipulated the frequency of prescribed fire to (a) an accelerated 2-yr interval or (b) a delayed 4-yr interval, and compared ecosystem responses between sites on sandy vs clayey soil and in lighter training (primarily dismounted infantry) vs heavier training (compartments open to mechanized training) area. We compared ground layer vegetation and nitrogen cycling over 5 years, which encompassed two 2-yr fire intervals and one 4-yr fire interval, to determine if these measures show thresholds beyond which combinations of military training and prescribed fire cannot be sustained.

Longleaf pine ecosystem is the desired future condition for upland forests on appropriate sites at Fort Benning. Under the assumption that a short (2-yr) fire interval is the external force that sustains a longleaf ecosystem, sandy or clay longleaf-dominated sites with lower or higher military use and in the 2-yr fire treatment provided ‘control’ or threshold values for transition to the longleaf ecosystem domain. We hypothesized that the more open environment generated by heavier training and frequent fire could promote regeneration of species typical of pine ecosystems, and hasten transition to a longleaf pine forest, provided species tolerate the disturbance legacy of mechanized military training. We also hypothesized that the magnitude of ecosystem response to fire and military training disturbance would be less, and the transition to pine-dominated forest faster, for sites on sandy soils because the pool of tolerant species is smaller and the successional pathway is shorter on these lower quality soils.

Baseline surveys conducted in 2000 and 2001 revealed that vegetation and soil conditions at the start of this research reflected land use and soil texture differences among the study sites.

A survey of disturbance features revealed that land use or natural disturbance features occupied from 7 to 50 percent of sample transect length. Clayey sites in heavy

military use areas had greater length of sampling transects in disturbance features. Road-like features, including active and remnant trails, roads, and vehicle tracks or trails, were, collectively, the most frequent and abundant disturbance.

Differences in soil properties among the 32 upland forest stands were related to soil texture and military land use intensity. Results suggest that organic layers in sandy compared to clayey sites could immobilize nitrogen through relatively slow rates of decomposition and nitrogen release to the mineral soil. In the mineral soil, field and laboratory results suggest that mineralization processes enhance nitrogen availability in sandy sites, especially in land compartments with heavier military training. In contrast to the sandy sites, greater organic layer mass in clayey sites, particularly in sites with lighter military use, favors faster decomposition, but the lower nitrogen availability observed in the field on the heavier use sites suggests mineralized nitrogen can be bound by fine soil particles.

Ordination, used to visualize patterns in vegetation composition, revealed a strong effect of military training on canopy and ground layer composition at the start of this research. The canopy tree ordination also reflected the proportion of pine, particularly longleaf pine. We distinguished four forest types, based on the dominant canopy trees: longleaf pine stands, shortleaf stands, mixed pine hardwood stands, and loblolly stands. Although differences were less pronounced than in the canopy, ground layer vegetation also reflected the canopy dominant. Pine-hardwood and longleaf stands had different ground layer composition. *Andropogon* sp., primarily broomsedge, *A. virginicus*, *Pityopsis*, and sweetgum (*Liquidambar*) seedlings were abundant in multiple canopy types. Pine-hardwood forests had abundant *Vitis* sp, while bracken fern (*Pteridium aquilinum*) was abundant in longleaf stands. The abundance of legumes and grasses was higher in the longleaf stands than in the other forest types. Over all forests types, 70 percent pine canopy appears to be a threshold for ground layer vegetation with abundant grasses and legumes.

Vegetation analyses after two 2-yr fire cycles and one 4-yr cycle revealed the shorter, 2-yr fire interval caused the ground layer vegetation to become more similar to that of clayey sites with heavier military use; i.e., to be characterized by more xeric sandhills species and nonwoody legumes, graminoids, and forbs. However, comparisons of ground layer composition between longleaf stands and those of the combined other (pine-hardwood, shortleaf, loblolly) forest types revealed that sites that were initially different did not converge over time. The shorter, 2-yr fire interval did not cause initially dissimilar sites to become more similar to, or initially similar sites to diverge from, longleaf communities. Although the shorter fire interval did not cause dissimilar sites to shift to longleaf, either (1) heavier military use or shorter fire frequency in clayey sites, or (2) shorter fire frequency in sandy sites can maintain ground layer composition similar to that of longleaf sites. These re-

sults partially support the hypothesis that the magnitude of ecosystem response to fire and military training disturbance would be less, and the transition to pine-dominated forest faster, for sites on sandy soils. Shorter fire frequency alone can maintain longleaf ground layer composition on sandy sites, but both shorter fire frequency and heavier military training may be needed in clayey sites.

Within the context of the Fort Benning ecosystem management model, the longer, 4-yr fire intervals in sandy sites or the combination of longer fire interval and lighter military use in clayey sites may cause sites to move away from the longleaf domain and lengthen the successional trajectory. In contrast, a 2-yr fire interval and heavier military use in clayey sites or the 2-yr fire interval in sandy sites may maintain sites within the desired longleaf understory domain. However, in sampled stands the more frequent burning did not result in high levels of legume abundance and associated N inputs, which could offset nitrogen losses due to fire. Further, more frequent burning did not promote longleaf regeneration sufficient to hasten transition to a longleaf pine forest. Longleaf regeneration was absent to low over all sites. Over half (57 percent) of marked pine seedlings (all species combined) died between 2001 and 2002; mortality was higher in longleaf stands and 2-yr fire frequency. Thus, despite promoting desirable understory composition, more frequent fire may inhibit regeneration. These results only partially support the hypothesis that the more open environment generated by heavier training and frequent fire could promote regeneration of species typical of pine ecosystems, and hasten transition to a longleaf pine forest. If seedling establishment limitation is overcome (e.g., by planting), management that maintains a relatively open canopy (prescribed fire, thinning) and low soil disturbance (lighter compared to heavier military training), can promote growth into grass, rocket, and sapling stages. In summer 2004, after all sites were burned following both 2-yr fire intervals and one 4-yr fire interval, the number of grass stage individuals in a stand increased with the number of historical fires (1980-2000), longer time since fire, and the percent of sand in the soil; the number of rocket stage individuals increased with increasing number of historical fires. These conditions were common in longleaf and shortleaf stands that had experienced higher fire frequency and forest management for an open canopy, but lighter military use.

In summary, military training and frequent fire have, over the longer term (decades), interacted with soil texture to influence forest canopy and ground layer composition, and soil conditions, at Fort Benning. Over the shorter term of our research (4 years), frequent fire (on sandy sites), or frequent fire combined with heavier military use (on clayey sites) can cause convergence toward 'sandhills' ground layer vegetation dominated by more xeric species, graminoids, and legumes, but these land uses are not sufficient to cause initially dissimilar sites to shift (cross a threshold) to longleaf pine understory. Management to restore longleaf pine forests must

overcome recruitment limitations and may be inhibited by frequent fire; recruitment of longleaf was nonexistent to low over all sites and seedlings/sprouts of all species were reduced by prescribed fire. If recruitment limitation is overcome, management that maintains a relatively open canopy and low soil disturbance can promote longleaf pine growth into grass, rocket, and sapling stages and may facilitate restoration of longleaf pine ecosystem as conceptualized in the Fort Benning ecological restoration model.

Conclusions

Baseline surveys conducted in 2000 and 2001 revealed that military training and frequent fire have, over the longer term (decades), interacted with soil texture to influence forest canopy and ground layer composition, and soil conditions, at Fort Benning.

- The survey of disturbance features revealed that land use or natural disturbance features occupied from 7 to 50 percent of the area sampled in each site. Road-like features, including active and remnant trails, roads, and vehicle tracks or trails, were, collectively, the most frequent and abundant disturbance. Disturbance features were most abundant in clayey sites in heavy military use areas.
- Differences in soil properties among the 32 upland forest stands were related to soil texture and military land use intensity. Results suggest organic layers in sandy compared to clayey sites could immobilize nitrogen through relatively slow rates of decomposition and nitrogen release to the mineral soil, but mineralization processes in the mineral soil could enhance nitrogen availability, especially in land compartments with heavier military training. In clayey sites, greater organic layer mass, particularly in sites with lighter military use, favors faster decomposition, but the lower nitrogen availability observed in the field on the heavier use sites suggests mineralized nitrogen can be bound by fine soil particles.
- Ordination revealed a strong effect of military training on initial (2000, 2001) canopy and ground layer composition. The canopy tree ordination also reflected the proportion of pine, particularly longleaf pine. We distinguished four stand types, based on the dominant canopy trees: longleaf pine stands, shortleaf stands, mixed pine hardwood stands, and loblolly stands. Although differences were less pronounced than in the canopy, ground layer vegetation also reflected the canopy dominant. Pine-hardwood and longleaf stands had different ground layer composition. *Andropogon* sp., primarily broomsedge, *A. virginicus*, *Pityopsis*, and sweetgum (*Liquidambar*) seedlings were abundant in multiple canopy types. Pine-hardwood forests had abundant *Vitis* sp, while bracken fern (*Pteridium aquilinum*) was abundant

in longleaf stands. The abundance of legumes and grasses was higher in the longleaf stands than in the other forest types. Over all forests types, 70 percent pine canopy appears to be a threshold for ground layer vegetation with abundant grasses and legumes.

Over the shorter term of this research (4 years) land use had measurable, but less pronounced effects on vegetation and soil.

- Vegetation analyses after two, 2-yr fire cycles and one, 4-yr cycle revealed the shorter, 2-yr fire interval caused the ground layer vegetation to become more similar to that of clayey sites with heavier military use; i.e., to be characterized by more xeric sandhills species and nonwoody legumes, graminoids, and forbs.
- Prescribed burning at Fort Benning reduces the soil organic layer, a largely immobilizing nitrogen pool in these systems. The removal doesn't represent a reduction in immediate nitrogen availability, but rather a reduction in total N pool. The longer-term consequences of this removal are not well understood and a long-term monitoring plan should address this to ensure the system doesn't trend toward nitrogen deficiency. Presently, on most sites, nitrogen fixation does not supply sufficient fixed nitrogen to offset these organic layer nitrogen losses.
- Comparisons between longleaf and initially dissimilar sites revealed either (1) heavier military use or shorter fire frequency in clayey sites, or (2) shorter fire frequency in sandy sites can maintain ground layer composition similar to that of longleaf sites. These results partially support the hypothesis that the magnitude of ecosystem response to fire and military training disturbance would be less, and the transition to pine-dominated forest faster, for sites on sandy soils; shorter fire frequency alone can maintain longleaf ground layer composition on sandy sites, but both shorter fire frequency and heavier military training may be needed in clayey sites.
- Comparisons between longleaf and initially dissimilar sites revealed the shorter, 2-yr fire interval was not sufficient to shift ground layer composition to the longleaf domain. Shorter fire interval did not cause sites that were initially different to become more like, or initially similar sites to diverge from, longleaf communities.

Within the context of the Fort Benning ecosystem management model and SREL's research design, the longer, 4-yr fire intervals in sandy sites or the combination of longer fire interval and lighter military use in clayey sites may cause sites to move away from the longleaf domain and lengthen the successional trajectory. In contrast, a 2-yr fire interval and heavier military use in clayey sites or the 2-yr fire interval in sandy sites may maintain sites within the desired longleaf understory domain. However, in sampled stands the more frequent burning did not result in high

levels of legume abundance and associated N inputs, which could offset nitrogen losses due to fire. Further, more frequent burning did not promote longleaf regeneration sufficient to hasten transition to a longleaf pine forest. Thus, despite promoting desirable understory composition, more frequent fire may inhibit regeneration. These results only partially support the hypothesis that the more open environment generated by heavier training and frequent fire could promote regeneration of species typical of pine ecosystems, and hasten transition to a longleaf pine forest. If seedling establishment limitation is overcome (e.g., by planting), management that maintains a relatively open canopy (prescribed fire, thinning) and low soil disturbance (lighter compared to heavier military training), can promote growth into grass, rocket, and sapling stages. In summer, 2004, after all sites were burned following both 2-yr fire intervals and one 4-yr fire interval, the number of grass stage individuals in a stand increased with the number of historical fires (1980-2000), longer time since fire, and the percent of sand in the soil; the number of rocket stage individuals increased with increasing number of historical fires. These conditions were common in longleaf and shortleaf stands that had experienced higher fire frequency and forest management for an open canopy, but lighter military use.

We conclude that management to restore longleaf pine forests must overcome recruitment limitations and may be inhibited by frequent fire. In addition, restoration of a more legume-dense groundcover would aid in nitrogen supply to these forests. If recruitment limitation is overcome, management that maintains a relatively open canopy and low soil disturbance can promote longleaf pine growth into grass, rocket, and sapling stages and may facilitate restoration of longleaf pine ecosystem as conceptualized in the Fort Benning ecological restoration model.

Products

Publications associated with this research team are included in Appendix A.

Professional Society Presentations in 2004

Dilustro, J., B. Collins, and L. Duncan. Soil nitrogen availability in mixed pine forests of varying management, military use and soil texture. Soil Science Society of America meeting, November, 2004.

Dilustro, J., B. Collins, L. Duncan, and C. Crawford. Soil respiration, microbial biomass, and fine root production in forests of varying soil texture. ESA meeting, Portland, OR, August, 2004.

Drake, S., J. Dilustro, B. Collins, and R. Sharitz. Groundcover carbon and nitrogen cycling in a frequently burned mixed pine forest. ESA meeting, Portland, OR, August, 2004.

Dilustro, J., B. Collins, L. Duncan, and C. Crawford. Soil respiration and fine root production in southeastern mixed pine forests of varying soil texture. ASB meeting, Memphis, TN, April, 2004.

Collins, B. Land use effects on vegetation and nitrogen cycling at Fort Benning, GA. Drexel University, January, 2004.

8 SEMP Integration Project (SIP)

2004 Annual Report

21 January 2005

PI: Virginia Dale

Collaborators: Amy Wolfe, Aaron Peacock, and Latha Baskaran, Oak Ridge National Laboratory

Summary of Overall Approach

(key elements are shown in Figure 8-1)

- *Information solicited from SEMP researchers and Fort Benning Resource Manger about criteria for selecting indicators.* Both the research teams and environmental management staff at Fort Benning were asked to project their comments on criteria for selecting indicators for the integration screen.
- *Query sent to SEMP researchers about indicators they are developing.* The five research teams were sent a questionnaire that queried them as to the key ecological indicators for the Fort Benning area as suggested by their data (e.g., the spatial extent of the data and the whether data already placed in ECMI).
- *Complied results of queries on proposed indicators.* The results of the queries were completed and were shared in a report to SEMP as well as with the research teams and Fort Benning staff. There was much review and discussion with the research teams and Benning staff before the report was completed to be sure that the terms were all explained clearly and that the information sources and caveats were properly described.
- *Preliminary screening of the criteria conducted for indicators.* The SEMP research teams and the Fort Benning resource managers were asked about the proposed criteria, and a revised set of criteria was developed. Each research team was asked to evaluate its indicators against the criteria.
- *Land management categories (LMCs) derived from existing land use groups and the Delphi method.* Using existing information and categories where possible, the research teams and Benning staff came to an agreement upon a set of land-management categories for the Fort Benning area. The Delphi method provided a means of achieving consensus among raters by providing feedback on other raters' responses. The final result is a set of land-management categories for Fort Benning that will likely transfer to other installations in the region that undergo similar land-use and management practices.

- *Key management needs identified for management screen.* Working with Jeff Fehmi and the Benning staff and using existing management protocols, the research teams identified the key ecological management needs of the installation. The time frame and spatial resolution as well as land-cover type and land-use conditions for each management need were considered.
- *Multivariate analysis is being conducted for the proposed indicators that make it through the first screen against LMCs.* Each research team assigned an LMC to each plot and thus each set of data. Then the data on proposed indicators were analyzed. The land-management categories were treated as independent variables in a multivariate analysis of the proposed indicators that made it through the first screen. We are in the process of determining how well the proposed indicators distinguish the land-use categories by using multivariate techniques (e.g., by creating dendrograms and conducting principal components analyses and neural net analyses).
- *Results of the second screening for management needs will be assessed.* The screening of the suite of indicators will be compared with management needs to identify any gaps in how the indicators relate to management needs. The potential impact of ongoing management on endangered species and their habitats and on environmental quality will be considered. Areas of redundancy in the indicators will also be identified, and benefits and costs of these redundancies will be discussed.
- *A monitoring and analysis plan is being developed.* This report will be developed by Jeff Fehmi and other CERL staff and will detail how the monitoring and analysis plan will be implemented at Fort Benning and how it can change over time to accommodate new information and new knowledge.
- *LMCs are being mapped.* Working in conjunction with the Fort Benning resource managers, we are developing maps of the components of the LMCs as described above. One key map is for the military uses of the installation. Another map depicts the land management goals and endpoints.

Procedure for Including Indicators in Decision Making Process
 = Research + Characterization + Management Needs

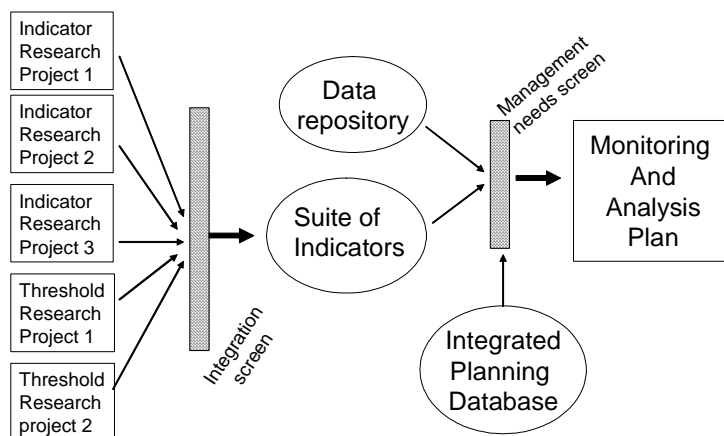


Figure 8-1. Diagram of the procedure to include indicators in the decision process by using information from three indicator research projects and two threshold research projects.

Previous Progress

(what steps were completed in FY03 and earlier)

During FY03 the LMCs for Fort Benning were derived according to the SEMP Integration Plan (SIP). These categories were developed by using the Delphi process involving Fort Benning resource managers and five research teams. Each research team assigned an LMC to each of its plots and shared data with us on proposed indicators.

Specific Steps Undertaken in FY04 and Methods Used on These Steps

The data on proposed indicators were organized according to the LMCs. This step required repeated discussions with representatives from each research team to make sure that data were correctly transferred and that the indicators were appropriately defined.

Initial statistical analysis of the data was completed in late 2004. In brief, 14 data sets that included 68 separate indicators were provided by the SEMP research teams. Data sets were integrated as much as possible in the beginning by combining indicators measured on the same plots by time. Screening of the indicators was accomplished by using SAS Enterprise Miner software. Multiple models (regression with different selection techniques, tree, and neural networks) were used primarily as variable selection tools. Of the original 68 indicators, 23 are being considered for

the next phase of the analysis. Although 23 indicators may seem high, several research teams measured the same indicators, and thus there is some replication in indicator type (e.g., soil carbon). This approach has afforded a semi-independent check on the validity of the selected indicators.

Discussions were held with Fort Benning resource managers about how indicators will be used in their management and planning activities. For management purposes, resource managers suggested that ideal indicators should do the following.

- *Help resource managers comply with environmental legislation, including the Endangered Species Act.* Indicators should signal conditions that threaten to undermine the installation's efforts to achieve compliance with its legal requirements.
- *Provide feedback on management practices.* The indicator should gauge the effectiveness of current resource-management regimes and should identify where the regimes should be modified.
- *Provide quantifiable management targets.* Quantification of desirable indicator values should help resource managers identify goals and should help institutionalize targets for the resource-management process.
- *Maximize the ratio of sampling effort exerted to information yielded.*
 - *Sampling design and effort should be proportionate to need.* The value of the information obtained should justify the level of resources (e.g., equipment, personnel, post-collection processing) involved in collecting it.
 - *Sampling measurement should be cost-effective.* Acceptable cost thresholds can vary according to how useful the indicator is otherwise.
- *Be comprehensive.* Ideally, a single indicator should provide information about a large area (e.g., watershed level rather than plot level) and about more than one resource (e.g., soil and water quality).

The LMCs are being mapped in order to provide a spatial interpretation of the categories developed. Two maps are being made for this effort. The first map, illustrating the land-management goals and endpoints, was created by using data from different sources, including the 2001 land-cover inventory, forest inventory data from Fort Benning, and a vegetation map from the Nature Conservancy. Three main categories were included in this map: minimally managed areas, areas managed to restore or preserve upland forests, and areas managed to maintain an altered ecosystem. Discussions with Fort Benning staff helped in uniquely assigning areas to these categories. The second map documents the cause of predominant ecological effect from military use of land. Different military training activities, such as using tracked or wheeled vehicles and firing ranges are mapped with respect to the area on which they are allowed to occur. Information on training activities and their re-

strictions were obtained from Fort Benning personnel and from Fort Benning environmental awareness training guidelines.

Problems and Issues

All the data from the SEMP research teams have not been obtained. In particular, the data collected for the site quality analysis were not sent to us despite numerous requests.

Current Status and Next Steps

In the coming year the LMC map will be finalized. The second map, which will document the cause of predominant ecological effects of military use of land, will also be completed. Different military training activities, such as using tracked or wheeled vehicles and firing ranges, will be mapped with respect to the area on which they are allowed to occur. Information on training activities and their restrictions has been obtained from Fort Benning personnel and the Fort Benning environmental awareness training guidelines and will be used to develop the map.

Statistical analysis of the indicator data will be completed within a month or so. The remaining portion of the analysis will take the indicators selected from the screening process and to assess their distribution over the LMCs. It is thought that the distribution information about the selected indicators within each LMC will aid in the management of the military land.

As the findings from statistical analyses become available, and as mapping proceeds, there will be another iteration with Fort Benning resource managers to verify that results continue to be meaningful and useful for practitioners. Refinements to the criteria for “good” indicators will be made at that point, based on interactions with resource managers.

Findings to Date

(what conclusions can be drawn at this point)

- A collective vision for the land can be derived among resource managers if care is taken to be sure that terms are communicated clearly and that all stakeholders have the opportunity to participate in discussions.
- Multivariate analysis supports the hypothesis that ecological indicators should come from a suite of spatial and temporal scales and environmental assets.

- Maps can be created that depict LMCs that cover both ecological interests and military land uses.

Critical Next Steps

(planned and recommended beyond plans)

The next step is to validate the procedure at another location. We have had some discussions with resource managers at Fort Bragg, and they are interested in developing and testing our procedure.

Products

Publications associated with this research team are included in Appendix A.

9 Development of a Site Condition Index: Southeast Upland Forest Focus

December 2004

Anthony J. Krzysik, Prescott College and Harold E. Balbach, U.S. Army ERDC-CERL

Introduction and Background

There is growing and widespread interest in developing terrestrial metrics or indices that assess landscape condition or are capable of monitoring long-term ecological changes. Terrestrial applications have proven difficult and lag far behind the two decades old stream-based IBI (Index of Biological Integrity) developed by Karr and his colleagues. Interest was shown by different U.S. Army installation natural resources personnel as well as management level persons from SERDP, the SEMP Technical Advisory Committee, and research personnel to develop a standardized approach and methodology to analytically quantify “habitat disturbance,” for the purpose of objectively assessing and comparing “landscape condition” across a wide variety of landscapes, while minimizing subjective judgments and bias among field investigators.

Researchers with SEMP projects at Fort Benning proposed and subsequently ranked habitat parameters they felt were ecologically valuable to assess landscape condition and disturbance. The final set of elements suggested to develop a Site Condition Index (SCI) consisting of: (1) Soil A-Horizon Depth, (2) Soil/Sediment Carbon, (3) Soil Compaction, (4) Vegetation Structure, (5) Species Composition, (6) Soil/Sediment Nitrogen, (7) Surface Cover (via remote sensing), and (8) Canopy Cover. This chapter investigates seven of these final elements for use in a composite SCI. The eighth, Species Composition, was not included because of technical problems in accurate identification of specimens. This drawback had been overlooked in the initial proposal process, and it is recognized that one of the important considerations for the design of an SCI is that it is easily derived without highly specialized training, including taxonomy.

The development of an SCI was based on the data obtained to develop Ecological Indicators to assist land managers in assessing and monitoring ecological processes and forest condition. This research was largely based on the SERDP project “Devel-

opment of Ecological Indicator Guilds for Land Management”, CS-1114B, as supplemented by information and suggestions from other SEMP research teams. The technical objectives and approach of CS-1114B were to develop Ecological Indicators based on disturbance gradients, ecosystem structure and processes, and unusual attention to analytical and statistical rigor. Multivariate and univariate statistical methods are being used to extract four levels of quantitative Ecological Indicator metrics: stand-alone variables, classes or groups of variables (e.g., Guilds), weighed combinations of variables, and multivariate vectors or variates. Statistical rigor was particularly stressed in three areas: (1) unbiased systematic-random sampling designs, (2) the minimization of Type I error, and (3) analyses with high statistical power. Analyses with high statistical power minimize Type II error, but require high sample sizes.

Field Methods

Ecological Indicators

The Ecological Indicators research was conducted at the U.S. Army’s Fort Benning, in west-central Georgia. Fort Benning lies in the Fall-Line Sandhills, an ecologically complex transition zone between Piedmont and Coastal Plain physiographic provinces, and includes the introgression of Loamy Hills from the west. The installation was exposed to agricultural land use prior to the 1940s, and has a long history of timber extraction. Landscape disturbance at Fort Benning reflects current mechanized infantry training activities and timber management, including active prescribed burning; and the historical template of row crop agriculture and extensive timber cutting. The research was conducted in two phases. Phase I research consisted of the evaluation of a very large number of potential Ecological Indicator systems in a reasonably uniform upland forest environment, differing only in current land use. This research took place in 2000, 2001, and 2002 (2001 and 2002 for habitat characterization) in two adjacent watersheds: Bonham Creek and Sally Branch. These Sandhill watersheds consisted of mixed pine/hardwood forest with sandy soils, and experienced pre-1940s agricultural land use. Nine research sites were selected in these watersheds, three each in High, Medium, and Low “disturbance classes” (DCs). High sites experienced current mechanized-infantry training activities. Medium sites experienced past training activities and are close to High disturbance areas, but are only impacted by foot traffic. Medium areas can be considered “recovering” sites. Low sites have not experienced military tactical vehicle maneuvers, have minimal foot traffic, and are being managed as safety buffers and for their conservation and wildlife values.

Phase II research was conducted in April and May 2003 to validate or test selected Ecological Indicators identified in Phase I that demonstrated high potential. Phase II sites were selected to represent the widest range of landscape disturbance and upland forest community types present at Fort Benning. Forty research sites for this validation were selected using information from eight GIS databases, the status of Fort Benning's "Unique Ecological Areas", all existing permanent SEMP research sites, and extensive final ground-truthing. The nine Phase I sites used by the CS-1114B project were included in the 40 sites, as were 13 of those established by the CS-1114E project. The other sites were either too small to accommodate the sampling design required, or were located close to or within ecological transitions and were considered not to be uniform enough for study as one site.

Field Sampling Design

At each site center point, four perpendicular 100-m transects were established from a randomly determined coordinate between 0-359 degrees. The random coordinate was identified using a pair of dice. All field data collected by all research teams were referenced to these four transects. The site center point was identified with two fluorescent pink flags. Each transect was identified with four fluorescent pink flags, placed at intervals of 25, 50, 75, and 100 m. Each flag was marked with its respective bearing and distance from site center. GPS center locations, transect bearings, and maps of all sites were provided to all research teams. Each site was classified based on visual disturbance to vegetation and soils, primarily caused by military training activities. Relatively pristine sites were classified as Disturbance Class (DC) 1, while the most degraded sites were classified as DC10. The individual doing the classification (Dr. Anthony J. Krzysik) had two decades of field experience with military training habitat disturbance. The classification was conducted before any field data were collected.

Soil A-Horizon Depth

A-horizon depth was systematic-randomly determined at 10 points along each transect from 10 to 100 m from the site's center, using a garden trowel and a 15-cm stainless steel metric ruler. Samples were taken in the identical quadrates that the ground cover samples were taken. See Ground Cover (following page) for details of sampling locations. Because of the difficulty and subjectivity involved in locating the base of the A-horizon, estimates were always made by the same surveyor to 0.5 cm. Sample size per site was equal to 40.

Soil Compaction

Soil compaction was determined systematically at 50 points along each transect from 2 to 100 m from the site's center using a Lang Penetrometer (Forestry Suppliers, Jackson, MS). Sampling was conducted approximately 1 to 2 m from alternating sides of the transect. Sample size per site was equal to 200.

Ground Cover (Includes Shrubs)

Ground cover and shrub cover were sampled on the four perpendicular site transects. Ten quadrats were systematic-randomly sampled on each transect from 10 to 100 m from the site's center. Sampling points were determined as follows. A pair of dice was thrown on the ground. The left die determined the side of the transect for quadrat location (odd number = left side, even number = right side). The value on the second die indicated the number of meters (paces) to place the sampling quadrat. Quadrats were placed after pacing. Therefore, the quadrat centers were randomly located approximately 1.5 to 8 m from the site transects. The quadrat consisted of a "hula-hoop" 86 cm in diameter (0.58 m²).

Percent cover was estimated for the following parameters:

1. Bare Ground
2. Pine Litter
3. Deciduous Litter (the sum of these three = 100%)
4. Forbs (total)
5. Legumes
6. Grass (total), includes sedge-like nongrasses
7. Ferns
8. Yucca
9. Cacti
10. Woody Plants (< 5 cm DBH, < 2 m high)
11. Identification and percent cover of each species or morpho-species.

Sample size of number of quadrats per site was equal to 40.

Canopy Cover

Canopy Cover was determined systematically at 2 points along each transect, 33 and 67 m from the site's center using a Concave Spherical Densiometer, Model C (Forestry Suppliers). At each sampling point, 96 "canopy hits/misses" were determined at each of four sighting positions 90-degrees apart. Therefore, there were

384 “canopy hits/misses” per sampling point, and 3072 per site. Sample size per site was equal to 8.

Basal Area

Basal area was determined systematically at 3 points along each transect, 30, 60, and 90 m from the site’s center using a Cruz-All Basal Area Factor (BAF) Gauge (Stock No. 59795, Forestry Suppliers, Jackson, MS). At each sampling point, BAFs of 40, 20, 10, and 5 were determined. In the database, the data were converted to m²/ha, and the largest value of basal area from the four readings was used as the final point basal area estimate. Sample size per site was equal to 12.

Trees

Trees were sampled on four perpendicular 100-m x 10-m strip-transects, that coincided with the four site transects. Trees whose centerline fell within the strip-transect were identified and measured with a 5-m fiberglass tape (Forestry Suppliers Inc., No. 59571). Diameter Breast High (DBH) was recorded to 0.1 cm, and only individuals with a DBH \geq 5 cm were tallied. Pine snags and deciduous snags were also measured. This data provided a number of site parameters: tree density, snag density, a direct measure of basal area, and floristic community composition of trees. These data could derive a large number of additional parameter estimates; for example, site characterization by species basal areas, species densities, or a number of dominance, similarity, or distance metrics.

Statistical Analysis

Statistical comparisons of habitat metrics among disturbance classes were assessed with Tamhane’s T2 multiple comparison test. This test is very conservative, therefore minimizing Type I error, and is the recommended procedure when variances are heterogeneous. All analyses were conducted with SPSS*.

* SPSS. 2003. SPSS software, version 12.0.1. SPSS, Inc., Chicago, IL.

Site Condition Index

Each variable that was used to calculate an SCI was first standardized by giving the specific variable a score of 100 at the site where this variable had its highest value, and then proportionately adjusting the values of that variable at each of the remaining 39 sites. Each habitat variable for this initial analysis was equally weighed. In future analyses, variables could be assigned varying weights of importance. Therefore, for a given SCI, the sum of all variable scores comprising the index was divided by the number of variables to arrive at a “mean value” for the SCI. The potential maximum value for an SCI was 100. But in order to achieve this value, each habitat variable comprising a given SCI would have to achieve its highest value at a single site.

Developing a Site Condition Index

Three habitat variables show potential for characterizing a broad landscape disturbance gradient based on the analysis of data from the 40 research sites. The promising variables are: A-Horizon Depth, Soil Compaction, and Bare Ground. Bare Ground is exactly related to litter cover, based on our field methods; Litter Cover = 100 – Bare Ground. Litter Cover will be used in this analysis because of its positive relationship with A-Horizon Depth. Canopy Cover and Basal Area will also be evaluated in SCI development, because they are important parameters, directly reflecting Southeast forest condition – canopy continuity and tree size.

Figure 9-1 shows the soil A-horizon depth at the 40 sites based on disturbance class. Standard errors are based on 40 samples per site. This translates to at least N=120 those DCs found at 3 sites, and N=280 for DC4 (found at 7 sites). This is required for the multiple comparisons analysis. However for the SCI analyses, N varies from 3 to 7, depending on the number of sites within specific DCs, because SCIs are based on comparing individual sites. An important observation in this figure was that the mean index scores for even the least-disturbed class (DC-1) achieved no more than half the maximum possible score. Figure 9-2 shows the 40 sites ranked by A-horizon soil depth and tree density for the same sites using the A-horizon ranking. The deepest soils were found at site J6 (a scrub oak pine savanna), and although moderately disturbed (DC4), was the only site that apparently was never plowed.

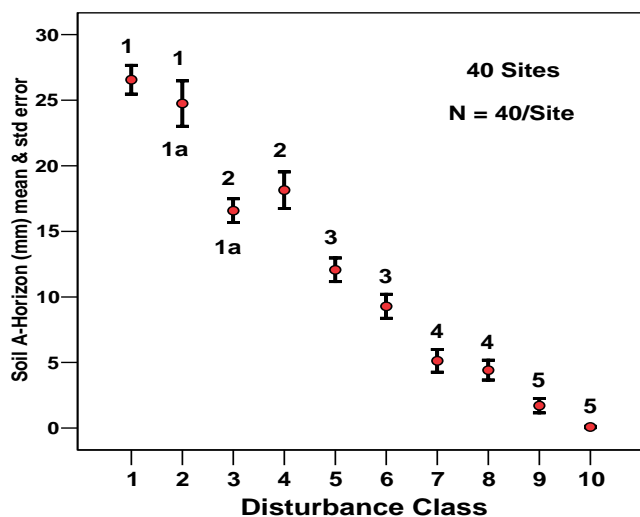


Figure 9-1. Soil A-horizon depth (mean and standard error) at the 40 sites based on disturbance class.

Numbers represent statistically similar disturbance classes.

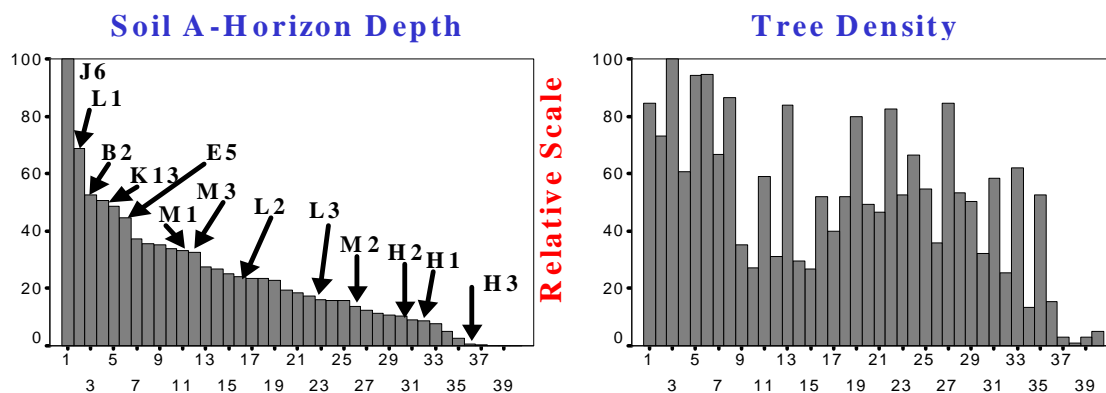


Figure 9-2. Tree density at the 40 sites (right), ranked by soil A-horizon depth.

Note that the ordinate is a relative scale where 100 is the maximum possible value.

The upland forests at Fort Benning represent a broad range of tree communities, although most are representative of “Mixed Pine/Hardwoods.” The use of cluster analysis and Nonmetric Multidimensional Scaling (NMS) ordination based on tree species basal areas identified 10 upland forest communities that could be represented on two axes; Axis 1: magnitude of basal area, Axis 2: a moisture gradient. Based on these results the 40 sites were placed into four Forest Moisture Classes. Most of the forests were mixed pine/hardwoods. In order to assess the effect of forest physiognomy or structure on the SCI, analyses were separately conducted on each of the four forest moisture classes using the five variable SCI. The highest forest moisture class consisting of a high deciduous forest component and Piedmont

Loblolly/hardwoods exhibited a very clear pattern. The mixed pine/hardwoods comprised the majority of sites and included representation from all 10 DCs. The long-leaf pine forests did not exhibit a consistent pattern on the disturbance gradient.

Despite the broad range of forest community types and habitat disturbance represented by the 40 sites, soil textures were surprisingly similar when soil textures were assessed over scales of 4 hectares. Ten sites had sandy loam soils, 27 had loamy sand soils, while 3 sites had sand textures. The latter two texture classes were combined into a “sandy” class. The SCI analysis was repeated for these two soil texture classes. The sand loam textures had higher clay contents than the sandy sites. Sand loam sites exhibited a relatively consistent pattern, with DC4 and DC5 being similar. The sandy sites, consisting of three-fourths of the total sample, not surprisingly, gave similar results as the 40-site data set.

A Survey of Other Potential SCI Variables

Figure 9-2 shows tree density at the 40 sites ranked in order of site A-horizon depth. The rank of A-horizon depth closely parallels site quality. The three most degraded sites completely lacked an A-horizon. Although the overall general pattern is a decrease of tree density as A-horizon decreases, there is a great deal of variability. Note that sites ranked closely together and therefore having similar A-horizon depths, may have dramatically different tree densities. Importantly, this can be the case along the entire disturbance gradient, from relative pristine sites, to moderately impacted areas, and to highly disturbed sites. Tree density would provide conflicting information in a SCI, is highly correlated with canopy cover and basal area, and adds no additional “habitat information” than already provided by canopy cover and basal area, variables that are already in the SCI.

Figure 9-3 shows soil nitrate (NO_3^-) at the 40 sites as ranked in order of site A-horizon depth. Despite the large differences among the 40 sites in habitat disturbance and forest composition, soil nitrate was relatively similar along the entire disturbance gradient, with the exception of three large anomalies and three smaller ones. The sites with high nitrate represent dramatically different communities: scrub oak – pine savanna (J6), oak-hickory deciduous forest (E5), Loblolly/Shortleaf – Hardwoods (D6-2). However, site D6-2 contains a section with a network of ravines with very large sweet gum and tulip trees.

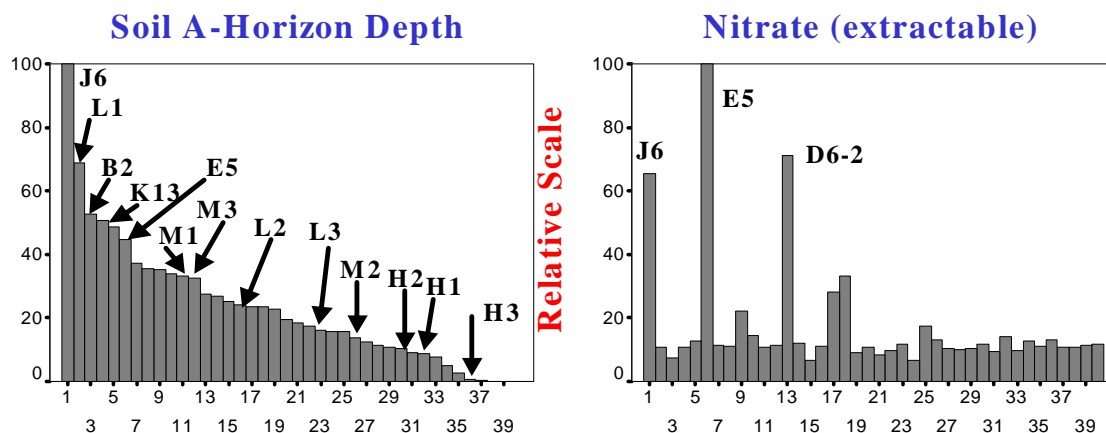


Figure 9-3. Soil nitrate (NO_3^-) at the 40 sites, ranked by soil A-horizon depth.
Note that the ordinate is a relative scale where 100 is the maximum possible value.

Figure 9-4 shows soil ammonium (NH_4^+) at the 40 sites ranked in order of site A-horizon depth. Unlike the general uniformity of soil nitrate, soil ammonium shows a general pattern of increasing along the disturbance gradient. The oak-hickory forest site (E5), as in the case of nitrate, again demonstrated the highest ammonium value. The interrelationships of nitrate and ammonium to each other, forest disturbance, forest community types, microbial activity, soil carbon, ecosystem nutrient leakage, and seasonal and weather influences are currently under analysis, and undoubtedly will require additional research in both detail and in a broader range of Southeast landscapes.

Figure 9-5 shows microbial carbon biomass (MCB) at the 40 sites ranked in order of site A-horizon depth. MCB is closely associated with available soil carbon, and therefore should closely track organic matter in the ecosystem. There is a general pattern of decreasing MCB with decreasing A-horizon depth and increasing disturbance. However, inter-site variability is high, even among sites possessing similar A-horizon depths. The four sites with the deepest A-horizons demonstrate moderate to low MCB. Sites J6 (DC4) and K13 (DC1) are scrub oak/pine savannas, site L1 (DC2) is loblolly/shortleaf hardwoods, and site B2 (DC1) is southern red oak/mixed pine (71 percent deciduous). The common theme in these four sites is a high percentage of deciduous trees and low disturbance. Although J6 is a DC4, it had the deepest A-horizon and was probably the only site that was never plowed. More analyses are being conducted on the soil carbon of our sites and relationships to microbial and nitrogen dynamics.

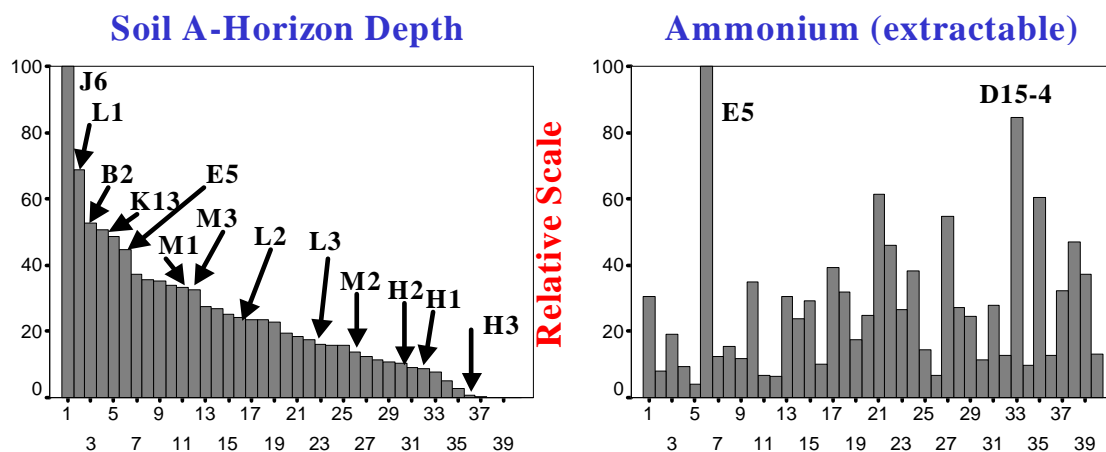


Figure 9-4. Soil ammonium (NH₄⁺) at the 40 sites, ranked by soil A-horizon depth. Note that the ordinate is a relative scale where 100 is the maximum possible value.

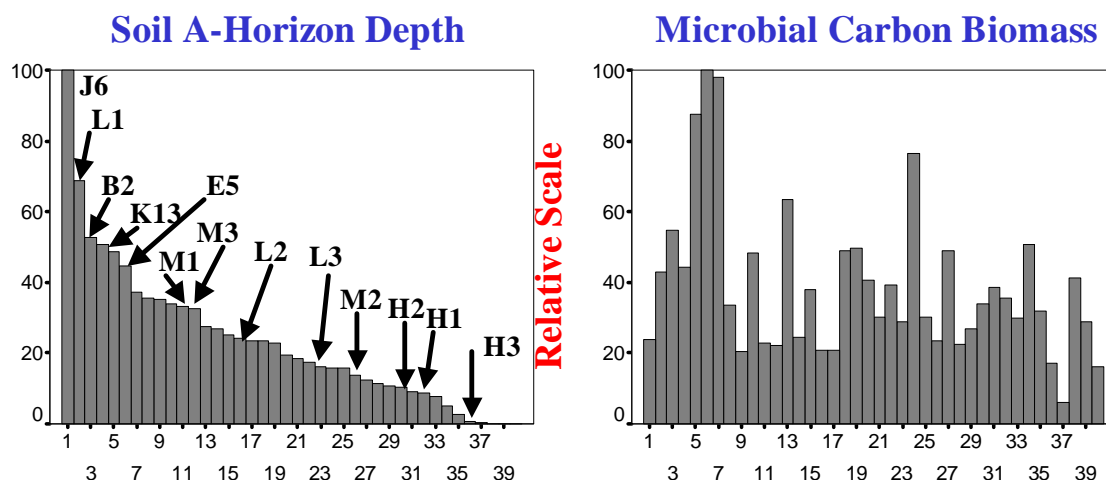


Figure 9-5. Microbial carbon biomass at the 40 sites, ranked by soil A-horizon depth. Note that the ordinate is a relative scale where 100 is the maximum possible value.

Site Condition Index – A Caveat

The dilemma in developing a multi-metric “Site Condition Index” is directly analogous to another “index of environmental quality” the diversity index. When one contrasts a reasonably large set of samples, both indices clearly reveal a significant correlation with disturbance or environmental impacts, and high quality sites are easily distinguished from poor quality sites. However, when trying to compare any two or several sites that are close together on a disturbance gradient, a significantly more important comparison than the extremes or a general overall trend, these multi-metric indices usually fail to elucidate innate important differences. This is because the index consists of a composite of metrics, where the relative contribu-

tions of individual metrics are obscured, confounded, and unknown, unless separately identified. For species diversity, this is the relative contribution of species richness and equitability (relative abundances of species). In other words, two sites can have the same species diversity, but innately possess two different patterns of community structure; high species richness with some dominance in one case, and lower species richness but more consistent relative species abundances in the other case. Similarly, a “Site Condition Index” composed of A-horizon depth, soil compaction, canopy cover, basal area, and litter cover (or bare ground), would mask individual contributions by each of these metrics; even though each of these are highly and statistically significantly correlated with each other and with disturbance along a broad disturbance gradient. There are also interesting relationships among the habitat metrics. For example, at the Phase II 40 sites, high canopy cover can be achieved by either high tree density or high basal area or some intermediate combination. A-horizon depth and soil compaction can be attributed to historical, recent past, and current specific habitat impacts. Therefore, teasing apart the relative contributions of temporal-based disturbances would most likely be masked by the substitution of a single composite index for A-horizon depth, soil compaction, and other habitat metrics.

Summary and Conclusions

A Site Condition Index (SCI) was developed using one to six parameters, with 6 separate indices resulting.

SCI Parameters Included

SCI1	soil A-horizon depth
SCI2	soil A-horizon depth, soil compaction
SCI3	soil A-horizon depth, soil compaction, litter cover (=100 - bare ground)
SCI5	soil A-horizon depth, soil compaction, litter cover, canopy cover, basal area
SCI6	soil A-horizon depth, soil compaction, litter cover, canopy cover, basal area, NDVI

Soil A-horizon depth alone was very effective at assessing the landscape disturbance gradient based on 10 disturbance classes. The addition of soil compaction to the index (SCI2) improved the index by reducing within-disturbance class variability and producing a better monotonic fit to the disturbance gradient. The addition of litter cover (or bare ground) (SCI3) not only did not improve the SCI, but degraded the interpretation of lower disturbance classes. The addition of canopy cover and basal area (SCI5) dramatically improved the monotonic relationship among moderately to

highly disturbed sites, DC5 to DC10. The addition of NDVI (SCI6) had no effect, and did not change this index compared to SCI5.

The best fit between a SCI and the 10 disturbance classes was based on only 2 parameters: A-horizon depth and soil compaction. However, the SCI based on five parameters (SCI5) provided the best “overall general assessment” of site disturbance condition. A-horizon depth as a stand-alone parameter was very effective at portraying the disturbance gradient, and this metric appeared to be the foundation for developing multi-metric SCIs for assessing landscape disturbance classes. The effectiveness of the SCI to assess disturbance classes was significantly improved by first classifying the upland forest communities into “forest moisture classes,” instead of applying it to all combined forest community types. The forest moisture classes were derived from cluster analysis and nonmetric multidimensional scaling ordination of sites based on tree species basal areas.

These initial results in developing a Site Condition Index from a wide variety of upland forest communities at Fort Benning are encouraging, and a great deal has been learned in this analysis. Nevertheless, the Fort Benning upland forests represent only a small portion of the Southeast landscape, and most of the sites are mixed pine/hardwoods on sandy soils. It would be desirable to examine mixed pine/hardwoods forests in other geographical contexts in the Southeast. Although the results in more mesic and more xeric forests are based on small samples and more narrow disturbance gradients, the general results paralleled those in mixed pine/hardwoods forests. Nevertheless, additional data is required to validate these initial conclusions. However, the longleaf pine forest sites produced anomalous results, possibly because of small sample size. Clearly additional samples are required for this important, but rapidly disappearing Southeast community type. In order to develop an optimal SCI it is necessary to acquire additional data on a greater variety of forest communities throughout the entire geographic range of Southeast forests. There is also the need for assessing the SCI in different soil textures, especially clayey soils.

10 Technology Transfer

Background

Federal agencies such as the U.S. Department of Defense (DoD) sustain healthy ecosystems and conserve ecological integrity through an ecosystem management approach. Although the DoD manages only about 25 million acres, or about 3 percent of Federal lands, the biodiversity of military lands makes them disproportionately valuable, especially in the southeastern United States where Federal public lands are scarce. While some military land uses are intensive and expose bare soil, significant acreage is used at low intensity or serves as buffer, and, as a whole, military land use maintains the ecological integrity lacking in urban, suburban, and agricultural settings.

DoD is committed to proactive ecosystem management of military lands and waterways. Installations in all of the services conduct active and often award-winning ecosystem management programs, supporting both the sustainable mission use of military lands and stewardship of the valuable ecological resources on these lands. In formal research requirements and through other mechanisms, all DoD services have expressed the need for better understanding of ecological processes and trends on military lands, the ecological relationship of military lands to their surrounding lands, and the interactions between mission activities and ecological processes. In response to these expressed needs, the Strategic Environmental Research and Development Program (SERDP) created the SERDP Ecosystem Management Project (SEMP) to pursue ecosystem research relevant to DoD ecosystem management concerns.

The overall program objective for SEMP is to plan, coordinate, execute, and manage, on behalf of the SERDP, an ecosystem management project initiative that focuses on ecosystem science relevant to DoD ecosystem management concerns. This objective includes:

1. Addressing DoD requirements and opportunities in ecosystem research:
 - Ecosystem Health or Change Indicators,
 - Thresholds of Disturbance,
 - Biogeochemical Cycles and Processes, and
 - Ecosystem Processes as they relate to multiple temporal and spatial scales.

2. Establishing and managing one (or more) long-term ecosystem monitoring sites on DoD facilities for DoD relevant ecosystems research;
3. Conducting multiple ecosystem research and monitoring efforts, relevant to DoD requirements and opportunities, at these and/or additional facilities; and
4. Facilitating the integration of results and findings of research into DoD ecosystem management practices.

Fort Benning became the initial SEMP host site in May 1998. It is located in west-central Georgia south of the city of Columbus, GA, and east of Phenix City, AL. It occupies approximately 73,533 hectares (ha) in Chattahoochee, Muscogee, and Marion Counties, Georgia, and Russell County, Alabama. In the ecological units proposed by the U.S. Forest Service, Fort Benning lies on the border between the Coastal Plains and Flatwoods-Lower Sand Hills ecological unit and the Coastal Plains-Middle, Upper Loam Hills ecological unit. Fort Benning falls within the Bailey's Subtropical Division.



Figure 10-1. Location of Fort Benning, GA.

Fort Benning was established in 1918. Prior to its use as a military facility, prehistoric people, Native Americans, and European-Americans occupied several sites on Fort Benning. The original site was a 38,600 ha plantation, but in response to the doubling of World War II troop strength, the U.S. Army purchased another 34,400 ha for training purposes. Currently Fort Benning is home to 12 major units and provides year-round training to over 100,000 troops.

The first of the two SEMP efforts is related to the need for monitoring. This long-term monitoring program has two main purposes: (1) to provide a basic set of background data that can inform the various research efforts, and (2) to provide installation managers basic information on overall ecological conditions and trends on the installation. While this monitoring program is not designed to specifically monitor

protected species or land restoration projects, monitoring data does provide measures that can be evaluated in terms of trends toward or away from broad ecosystem management goals. In addition, promising observations (or indicators) from the research projects that more specifically address measures of trends to or away from installation goals can be incorporated into the baseline monitoring program. Selected parameters will be monitored for 10 or more years through the developing ECMI system, in addition to those monitoring activities transferred to the installation for long-term monitoring at the conclusion of the SEMP research projects. Long-term monitoring offers sufficient temporal depth to allow interpretation of trends. The SEMP monitoring data will be supplemented with and potentially integrated with longer-term information from other available studies in the southeastern United States. For many relevant and urgent ecological questions, it will be difficult to determine trends within the SEMP timeline, but SEMP will provide the foundation for future extrapolation and prediction.

The second of the two SEMP efforts, the research component, includes five research teams pursuing one of two specific hypotheses. These hypotheses address questions: “what are good indicators of change, and what do these potential indicators reveal” and “what are the ‘thresholds’ of resources needed to avoid resource degradation?” A team including Fort Benning, DoD ecosystem managers, academics, and nongovernmental organizations generated these questions. However, once complete, the research outcomes will be packaged as research products independent of any specific management concern, action, or program conducted on a DoD installation. To execute the technology transition process, the research products must be translated into adoptable management and monitoring options along with all the information needed to incorporate them into current management processes. Then, the lessons learned from a single installation’s success will form the basis for packages targeting business processes in other locations.

Objective

There are three main products from SEMP for technology transition: research outcomes, candidate indicators, and lessons learned. Research outcomes include the monitoring protocols, research results, and monitoring trends (with each effort including all the source data in the repository). These research outcomes will become increasingly valuable to the installation as they are published and as the implications make their way through the planning cycle and become funded. Recommended indicators as identified by the integration effort represent the subset of research outcomes that monitor the environmental parameters associated with the requirements identified by DoD (or, more simply the linkages between research outcomes and user requirements). Criteria for ecological indicators include: ease of

measurement, high sensitivity, predictable response, low variability, and low cost among others. The lessons learned are the analysis tools for ecosystem trends, information about strategies of how to allocate monitoring activities, and how to manage research on installations.

The technology transition plan will be considered successful if it meets the needs of users and finds wide-scale adoption. The sponsor of the SEMP effort is SERDP. The SERDP technology transition goal for SEMP is “facilitating the integration of results and findings of [SEMP] research into DoD ecosystem management practices.” The potential users of the research occur across the depth and breadth of the DoD organization. From local to national, these organizations include Fort Benning, the Installations along the Fall-line, the Major Army Commands (MACOMs), the Army Installation Management Agency (IMA), the Army secretariat level, SERDP, and DoD. The best measure that the transition has been successful is that there is a comprehensive, concentric spread of research and monitoring lessons from Fort Benning outward. In order to ensure such success, the public and ongoing feedback need to be included throughout the process.

Approach

Technology transition is planned to occur in three phases: Fort Benning, DoD Installations along the Fall-Line, and beyond DoD. Fort Benning has been the site for the majority of work to date and will form the template for work elsewhere. As the template, current work on the technology transition is 80 – 90% focused toward Fort Benning. Work on the remaining phases will take the forefront after the transition to the host has been worked out in some depth. As transition begins to move to the Fall-line, coordination with the IMA and MACOMS (the next level of management above the installation) must become a stronger focus. The research for this phase is already under way through the Fall-line projects, which include all the services, not just the Army. This broader application is partially due to the generally regional applicability of much ecological research combined with the other services installations proximate to the Fall-line. The final phase is to make the SEMP monitoring and data available to some of the national networks (e.g., Long Term Ecological Research, National Ecological Observation Network) and other resource management agencies (e.g., US Department of Agriculture, US Department of Interior).

Technology transition is being completed at two organizational levels for each of the three phases. At the individual project level, each research team is working to transition their specific results. At the SEMP organizational level, the synthesized outcomes and technology from all SEMP efforts, including the research projects and monitoring, have technology transition plans.

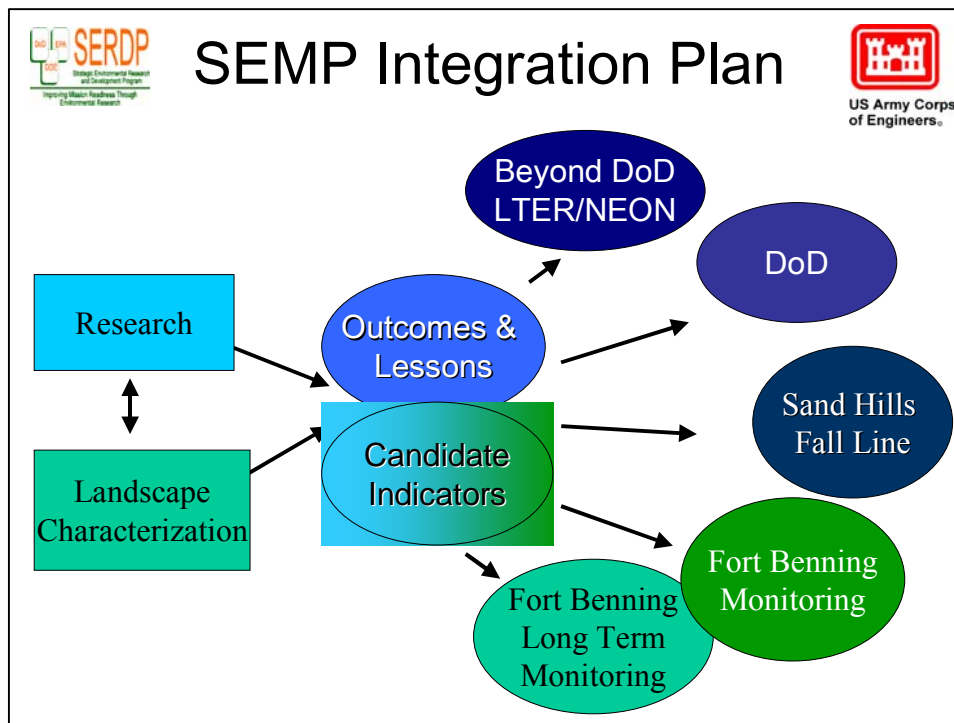


Figure 10-2. The SEMP and SERDP research and characterization work at Fort Benning becomes Ecological Indicators.

These indicators feed directly into the monitoring activities at the installation. The research and characterization also generate outcomes (products) which are useful beyond the installation. The lessons learned from applying this research at Benning are also valuable for efficiently and effectively establishing research at new military installations. The Technology Transition Plan is some piece of the arrows between the boxes and bubbles – ensuring that the information gets all the way to the people that can use it.

Determination of Indicators of Ecological Change (CS-1114A-99)

The principal investigator for this project is Dr. Ramesh Reddy from the University of Florida, Gainesville, FL.

Technology Transition Plan

Application of results and transfer of information and technology are critical elements of developmental research programs. The research effort will provide extensive scientific information and management tools, for specific use at Fort Benning and other military reservations in the southeast, as well as for wide application in a variety of ecosystems in other geographic regions. Development of ecological indicators is a high priority for the US Environmental Protection Agency, USDA, and other federal and state agencies. Thus, the list of potential users is extensive. We are pursuing several pathways for research transfer to end users, including:

- Development of a spatial database, including GIS coverages, of ecological indicators at the Fort Benning study site will provide the resource manage-

ment team of Fort Benning with invaluable technical information and tools to supplement their existing information base.

- Workshops or other forms of training provided for resource management personnel within and outside of DoD, to demonstrate field and laboratory methods for measuring selected ecological indicators.
- Extension publications and popular articles discussing the concepts and applications developed by our research team, directed at policy makers, educators and the general public.
- Scientific journal articles to provide technical results to the scientific community.

Development of Ecological Indicators for Land Management (CS-1114B-99)

The principal investigator for this project is Dr. Anthony J. Krzysik, Prescott College, Prescott, AZ.

Technology Transition Plan

Field data and models derived from this project will be made available to Fort Benning Data and models will be published in peer-reviewed scientific journals and will be presented at scientific and military meetings, including the annual SERDP Symposium.

Indicators of Ecological Change (CS-1114C-99)

The principal investigator for this project is Dr. Virginia H. Dale from Oak Ridge National Laboratory, Oak Ridge, TN.

Technology Transition Plan

A key part of the research program on Ecological Indicators is to transfer the results of the research to the management and research community. Our plan has been to develop indicators of ecological change that can become a part of the ongoing monitoring effort at Fort Benning. Therefore, in the research process we have been and will continue to work closely with Fort Benning and Nature Conservancy personnel (hereafter called environmental managers) who are involved in the research and monitoring programs.

Our first step was to establish criteria for indicators to be repeatable, statistically valid, indicative of changes, and readily measured by the environmental managers. These criteria were widely reviewed and are now published.

The integration of information into management is being given special attention. The best test of the success in this project is to have the environmental managers begin to use these metrics within the research time so that feedback can be achieved (in an adaptive management sense) within the time that the research is still ongoing. We are working very closely with the Fort Benning staff and The Nature Conservancy in this effort so that the research effort can contribute to workable management and monitoring plans.

One technology transfer product is already available. A booklet was designed to assist environmental managers in field identification of plant life forms and families that are important indicators of understory conditions at Fort Benning. A copy of the field guide has already been sent to environmental managers at Fort Benning.

By publishing our results in the scientific literature, we are asking the scientific community to peer review the proposed indicators. Hence we have an active publication policy within the project.

Our final project report will include the basic elements of technology transfer. For each set of indicators (landscape, vegetation, stream chemistry and biology and soil macroinvertebrates), our technology transfer plan will include: (1) clear definition and descriptions of each indicator, (2) sampling protocols, (3) laboratory protocols, and (4) suggested data analysis and interpretation guidelines.

Disturbance of Soil Organic Matter and Nitrogen Dynamics: Implications for Soil and Water Quality (CS-1114D-00)

The principal investigator for this project is Mr. Charles Garten, Jr., from Oak Ridge National Laboratory, Oak Ridge, TN.

Technology Transition Plan

The GIS being developed by existing SERDP projects at Fort Benning will be used to support this effort. Field data and models developed during the course of the project will be made available for incorporation into the Fort Benning GIS that is maintained by the US Army Engineer Research and Development Center on behalf of Fort Benning. Data and models will be published in peer-reviewed scientific journals and will be presented at scientific and military meetings, including the annual

SERDP/ESTCP Symposium. The project data and results will be incorporated into ORNL's SERDP website.

Thresholds of Disturbance: Land Management Effects on Vegetation and Nitrogen Dynamics (CS-1114E-00)

The principal investigator for this project is Dr. Beverly S. Collins from Savannah River Ecology Laboratory, Aiken, SC.

Technology Transition Plan

The information obtained from the proposed research on ecological effects of management practices will be directly communicated to the resource managers at Ft. Benning via interim and final reports. We will work with the resource managers to develop adaptive management practices based on our results.

The proposed research was also designed to support, but not duplicate, currently-funded SERDP-SEMP research. The research team, including scientists at SREL, UNC, IES, and SRI, hope to collaborate with the other SEMP research groups. We have contacted the lead PI of the other Year 2000 start (Garten) to initiate collaboration in nitrogen cycling measures. We agree to contribute data from the SEMP research to the SEMP data repository.

Results of this research (including the results for the in kind research on the SRS) will also be communicated to DOE-SRS and considered by SRI when developing timber prescriptions, natural management plans, and for adaptive management of SRS resources. We will communicate our results to natural resource managers at other military installations in the southeast that manage upland systems for long-leaf pine (e.g., Ft. Gordon, Ft. Jackson).

Finally, we will communicate the results of our research to the professional community through peer-reviewed papers.

11 Digital Multi-Purpose Range Complex

Final Report 2004

PIs: Hugh Westbury, D. Price, M. Sharif, and P. Mulholland

Fort Benning is constructing and will operate and maintain a Digital Multi-Purpose Range Complex (DMPRC) in the Pine Knot Creek, Sally Branch, and Bonham Creek watersheds. These watersheds were the also focus of ecological research coordinated by SEMP.

The DMPRC will provide a state-of-the-art range facility, meeting the installation's training needs for conducting effective gunnery exercises in a realistic training environment the Bradley Fighting Vehicle (BFV), the Abrams M1A1 Tank System (Tank), and currently developing future systems (such as the Stryker vehicle). Existing facilities at Fort Benning do not currently meet training standards for BFV and Tank training for "full" Table XII of gunnery qualification.

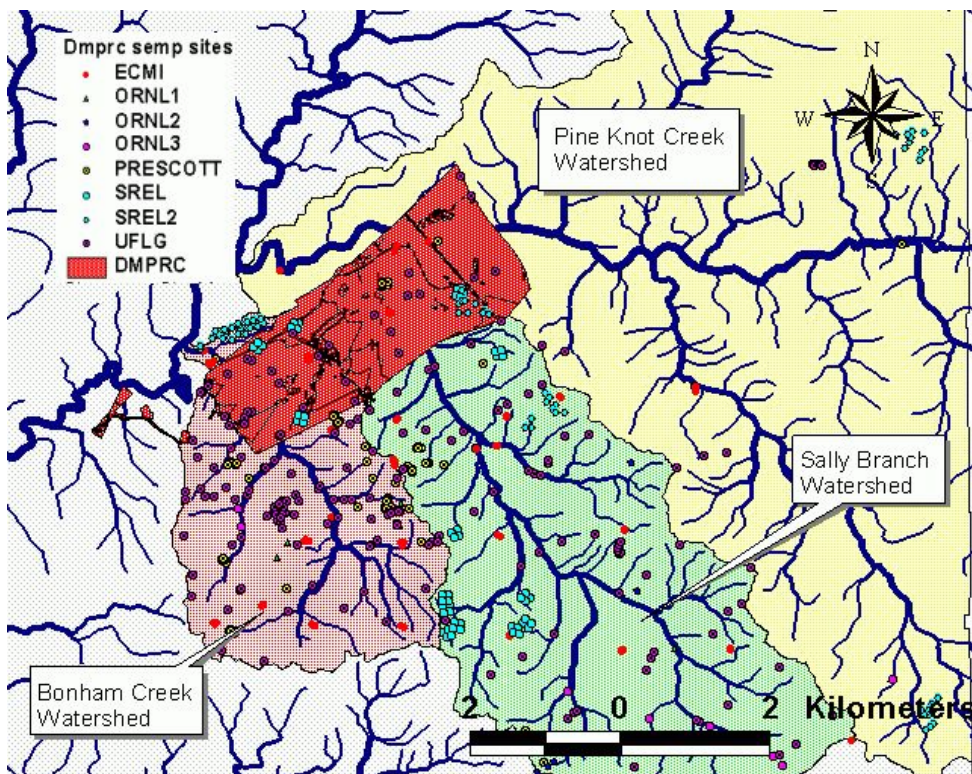


Figure 11-1. Location of all SEMP sites in affected watersheds.

The DMPRC is an approximately 1,800-acre firing range made up of four lanes approximately 250 meters wide. The DMPRC will create a Surface Danger Zone (SDZ), extending across Buena Vista Road into the K-15 Impact Area that will be inaccessible during operation of the range. Tanks and BFVs will use four low-water crossings (150-350 feet long by 29 feet wide) along Bonham Creek and four low-water crossings (same dimensions) across Sally Branch, for a total of eight crossings. Additionally, there may be as many as eight tributary crossings.

Support facilities associated with the DMPRC would be located in an adjacent complex and will consist of a Control Building, an After Action Review (AAR) building, latrines, BIVOUAC pads, a helipad, two general instruction buildings, an operations and storage building, a central maintenance building (for target maintenance only), an ammunition breakdown building with ammo dock, a bleacher enclosure, a covered mess, vehicle holding and maintenance areas, a well-house and water distribution/collection/treatment system, and a secondary power and data distribution system.

Construction of the DMPRC and its associated support facilities will result in the displacement of approximately 1.5 million cubic yards of soil and the clearing of up to 1,500 acres of trees, bushes, and shrubs. The Environmental Impact Statement (EIS) concluded that DMPRC construction will have a temporary minor adverse effect on water quality, cultural resources, and air quality as the result of earth-moving and grading requirements for the construction of the DMPRC. Temporary significant adverse effects to soils and vegetation will also occur as a result of earth-moving activities and tree clearance for the DMPRC and its associated support facilities. Permanent minor adverse effects will occur to Unique Ecological Areas (UEAS), wetlands, state protected species (gopher tortoise), and land use. Permanent significant adverse effects will occur to a federally protected species, the Red-cockaded Woodpecker (RCW), through loss of approximately 995 acres foraging habitat.

Fort Benning Environmental Management Division requested that SEMP/SERDP provide pre- and post-construction data to support the National Environmental Policy Act (NEPA) and National Pollutant Discharge Elimination System (NPDES) regulatory requirements. Additional support was sought for RCW recovery issues, monitoring Best Management Plan effectiveness and mitigation project planning and monitoring. The Final EIS and Record of Decision can be viewed on-line at the Fort Benning Environmental Management Division Homepage:
http://www-benning.army.mil/EMD/_program_mgt/legal/index.htm

DMPRC Charette

ERDC-CERL sponsored a workshop at Fort Benning on 15 and 16 June to develop a proposed monitoring plan and ecosystems technology demonstration in response to the construction and operation of the DMPRC. The primary goals of the meeting were to identify those issues of greatest importance to the installation and determine what data collection requirements must be fulfilled prior to the start of construction. The DMPRC offers an opportunity to demonstrate ecosystems technology to support future training and land management requirements.

Field trips to familiarize everyone with the DMPRC area were conducted on 14 and 15 June. The opening session of the workshop focused on identifying the regulatory needs of the installation for DMPRC. Gary Hollon discussed the erosion and sediment transport issues that have been identified by the Environmental Protection Agency (EPA) in their comments on the EIS. Michael Barron addressed the concerns of U.S. Fish and Wildlife Service regarding the direct impacts to RCW clusters as well as the effect of displaced birds moving into the foraging habitat of colonies not directly affected by the DMPRC.

In round-table discussions held over the next 2 days, SEMP/SERDP and ERDC researchers described the data they have collected to address these issues and additional steps they could take to better support the installation and capitalize on this research opportunity.

The Ecosystem Characterization and Monitoring Initiative (ECMI) has collected bi-monthly water parameters at two locations within the DMPRC beginning in 2001, and has continuous data for temperature and water level in Bonham Creek and Sally Branch. They have also conducted the EPA Rapid Bioassessment Protocol surveys for stream characterization at numerous sites affected by the DMPRC project. ECMI proposed additional RBP studies and supplemental water quality monitoring stations to better monitor the affected watersheds.

The University of Florida (UF) project collected soil and vegetation data at 29 sites within DMPRC and numerous locations in the affected watersheds. They also conducted soil moisture, hydrology, and bird studies within the footprint. This data could be used to characterize the uplands within DMPRC. UF also developed multi spectral scanning as a means of quantifying sedimentation in the riparian areas.

Table 11-1. SEMP data collection sites in the Sally Branch, Bonham Creek and Pine Knot Creek watersheds.

Project	Type of Investigation	Sally Branch	Bonham Creek	Pine Knot Creek
UFLG	Soil Biogeochemistry	0	12	2
	Hydrology	2	21	15
	Vegetation/soil survey	55	60	29
	Soil MSS	5	20	5
	Bird Survey	4	5	4
PRESCOTT	Macroinvertebrates	2	2	3
	Indicator Guilds	3	6	0
	Site Condition Index	17	13	1
ORNL1	Soil	0	4	0
	Stream chem./Aquatic Ecology	2	2	1
ORNL2	Soil chemistry	6	1	0
ORNL3	Riparian Veg and Soil	6	2	0
	Stream chem./Aquatic Ecology	3	2	1
SREL	Vegetation/Biogeochemistry	10	3	1
SREL2	Sandhill Habitat	20	29	21
ECMI	Soil Erosion/Deposition	12	10	4
	Weather Station	0	0	1
	Water Monitoring	1	1	1
	RBP	3	2	4

The Prescott College team collected a large suite of indicator guild data at nine sites in the affected watersheds. They also tested a subset of the indicators at nearly 30 sites in the Bonham and Sally Branch watersheds as a means of developing a site condition index. This team proposed to use the DMPRC construction to further validate and refine the most promising indicators of site condition.

The Oak Ridge National Laboratory projects (ORNL1 & 2) collected extensive water quality data on two tributaries to Bonham Creek that will be within the DMPRC footprint. They proposed to use the DMPRC construction to test the sensitivity of the ecological indicators suite selected as part of the SEMP Integration Project (SIP).

The Savannah River Ecology Laboratory (SREL) project had 13 sites in the affected watersheds, with 4 stations within the DMPRC footprint. These sites were sampled annually for an extensive suite of habitat variables. SREL proposed to resample these sites during and after construction as a means to monitor impacts to upland areas.

The SERDP-funded Riparian Restoration Project (ORNL 3) had stream-monitoring sites on the same Bonham Creek tributaries used by ORNL 1 and UF. This group

proposed an extensive study to assess construction affects on riparian vegetation and soils, stream hydrology and chemistry, as well as stream biota and habitat.

ERDC proposed an erosion and transport model to further address the sediment issue. Muhammad Sharif is developing a plan to relate sediment transport to turbidity, which will then be acceptable to the EPA as an easily measured estimate of sediment load, and to initiate an installation-wide erosion-stream sediment study. Bob Lozar proposed using the construction of DMPRC to demonstrate and refine the upland monitoring using hyper-spectral imagery obtained from the Earth-Observing satellite.

The various proposals were prioritized so that available funding could be secured and distributed. Efforts to monitor stream water quality were deemed to be of the highest priority. Two efforts could be started without additional funding — ECMI agreed to modify their RBP effort to capture the effects of construction on the streams, and ORNL 3 agreed to extend some of their effort to include Bonham Creek and Sally Branch. ERDC continued to develop a joint proposal that will fund additional efforts in FY05.

Work to Date

ORNL 3 received funding from SERDP in August 2004 to begin monitoring the effects of DMPRC timber harvesting and construction on riparian vegetation and soils, stream hydrology and chemistry, and stream habitat and biota. For the riparian vegetation and soils effects studies they have chosen one reference plot and four plots within the area to be disturbed by DMPRC activities within the Sally Branch and Bonham Creek Watersheds. Riparian measurements include sedimentation rates, vegetation species composition, structure, and productivity, soil physical properties and nutrient dynamics. Figure 11-2 shows the monitoring site locations for all the studies.

For the stream studies, they have chosen stream locations upstream and downstream of the DMPRC area in Sally Branch, Bonham Creek, and a small unnamed tributary of Bonham Creek that we have been studying as part of the SERDP Riparian Ecosystem project. Stream measurements include storm hydrograph recession constants, stream chemistry during baseflow and stormflow periods (suspended sediments, pH, NH_4 , NO_3 , PO_4 , DOC, Cl, and SO_4 concentrations), streambed stability and organic matter (coarse and fine), periphyton biomass and diatom assemblage structure, benthic macroinvertebrate assemblage structure and biomass, and fish diversity, dominance, and size structure. The water chemistry measurements

were begun in May 2004. The riparian and other stream measurements were begun in autumn of 2004. These studies are continuing at least through 2005.

ECMI used their regular fall RBP sampling to more fully characterize the affected streams prior to construction. They will resample these sites in FY05 in order to document any changes to the stream ecology that can be identified using this method.

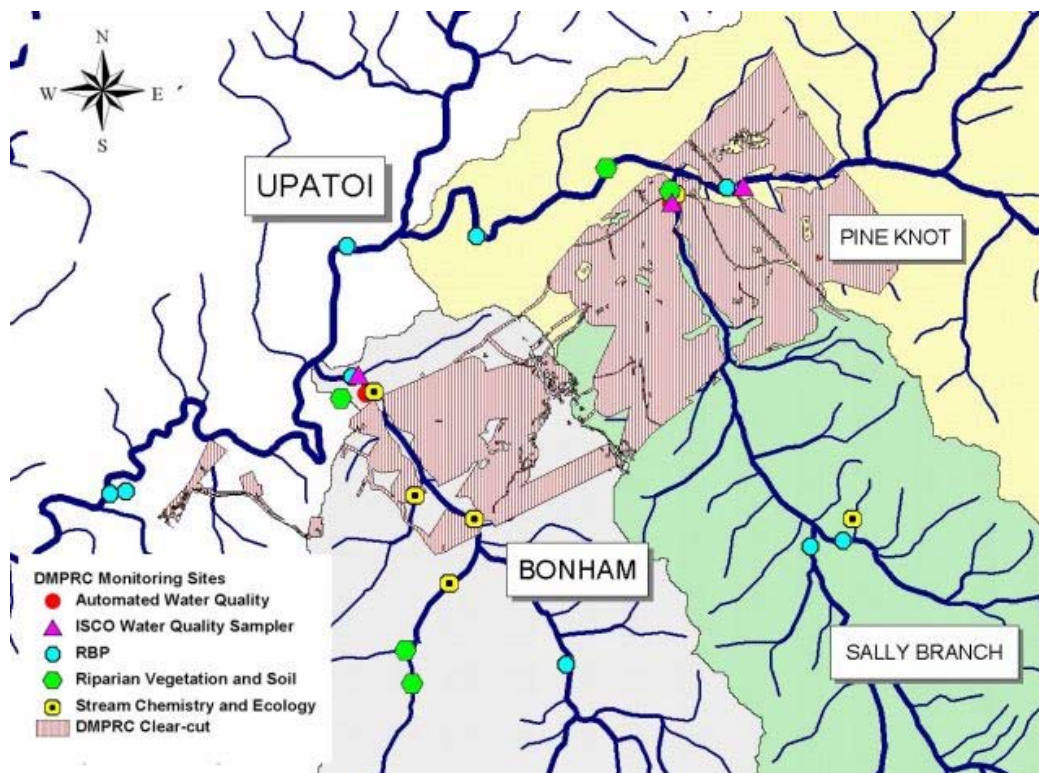


Figure 11-2. DMPRC monitoring site locations.

Fort Benning provided funding, personnel and other support for the ERDC sediment transport study (Muhammad Sharif, PI). Four large metal security boxes, four ISCO programmable water sampler and three YSI multi-probes were moved from Fort Bragg to Fort Benning and installed in Bonham Creek, Sally Branch, Pine Knot Creek, and Upatoi Creek. These samplers collect water samples during storm events (when sediment transport is highest) for subsequent analysis. Samples from the Bonham Creek and Sally Branch stations are split and shared with the ORNL3 project.

The purpose of this project is to establish permanent monitoring sites and, by comparing data collected by ISCO samplers, YSI multi-probes, ECMI RBP surveys, and ECMI automated water quality monitors (Bonham Creek and Sally Branch), develop a better understanding of the relationship between sediment transport and

turbidity. This data should enable easily collected turbidity measurements to be used as a surrogate for suspended sediment, which is difficult to measure. This effort will be expanded beyond the streams affected by the DMPRC construction to include Randall Creek, Ochille Creek, and two additional locations on Upatoi Creek.

During summer of FY04, field soil samples were collected for developing an empirically-derived turbidity-sediment transport model under laboratory-controlled conditions. Results showed highly significant correlations with linear regression equations as shown in Figure 11-3, Figure 11-4, Figure 11-5. These results strongly suggest that turbidity can be used as a surrogate to estimate suspended sediment concentrations and sediment transport loads in Fort Benning streams.

In co-operation with Fort Benning, a network of eight sediment-turbidity monitoring stations has been established to calibrate the empirical model derived under laboratory-controlled conditions. Three of these Isco monitoring stations are installed at Bonham, Sally Branch, and Pine Knot creeks to represent erosion-sediment transport loads from and around DMPRC watersheds. Another three Isco-YSI sampling stations are installed on Upatoi River, and one each at Ochillee Creek and Randall Creek. The real-time continuous water quality data collected by Isco-YSI samplers is accessed on request using digital cell phone telemetry for processing, management, and archiving. The Isco samplers are programmed to collect sediment samples for each storm event, and store a real-time continuous record of stream flow and several water quality parameters such as temperature, DO, pH, conductivity, NO₃-N, salinity, and turbidity.

Figure 11-3, Figure 11-4, and Figure 11-5 show sediment concentration relationships as a function of turbidity for three soil types of Fort Benning. Sediment-turbidity regression equations are given at the bottom of each graph. Figure 11-6 and Figure 11-7 are typical graphs of stream level, flow velocity, and turbidity during some storm events at one of the sites at Upatoi River.

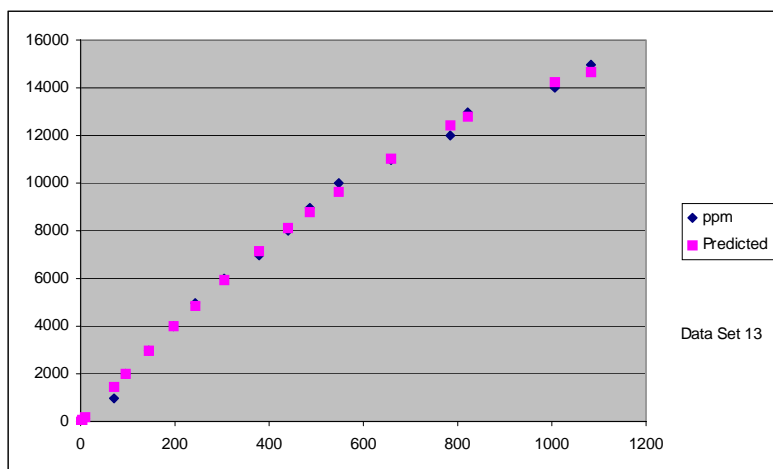


Figure 11-3. Sediment Concentration, $C_{sed} = 15.613 * TNTU$ ($R^2 = 0.987$) - Sandy Soil.

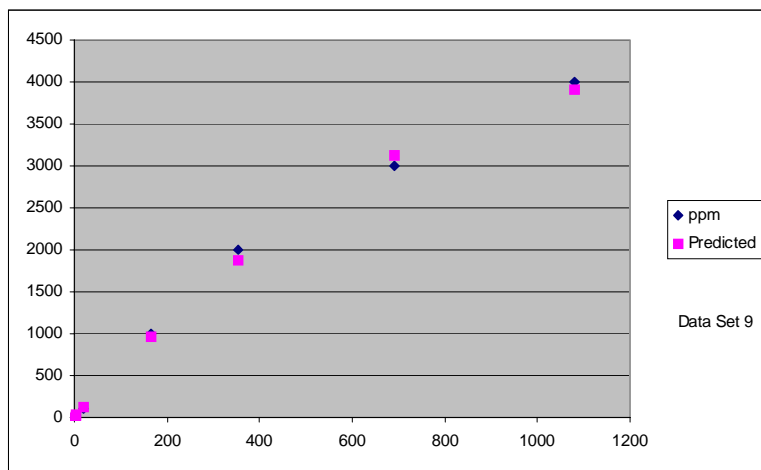


Figure 11-4. Sediment Concentration, $C_{sed} = 4.04 * TNTU$ ($R^2 = 0.998$) - Loamy Sand.

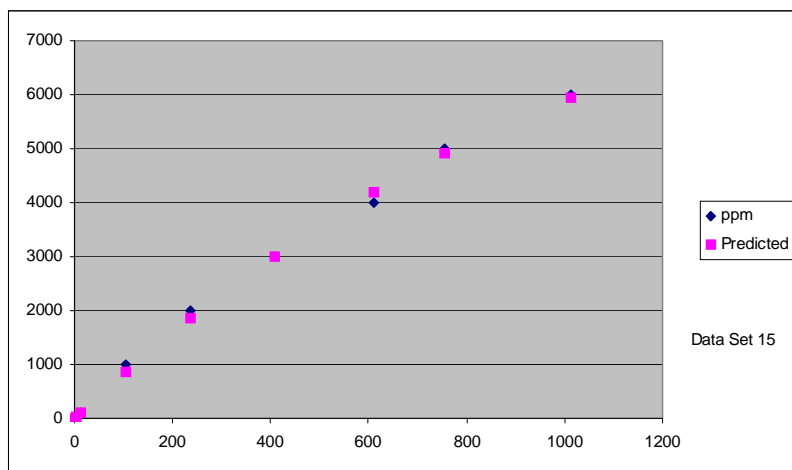


Figure 11-5. Sediment Concentration, $C_{sed} = 6.40 * TNTU$ ($R^2 = 0.988$) - Sandy Loam.

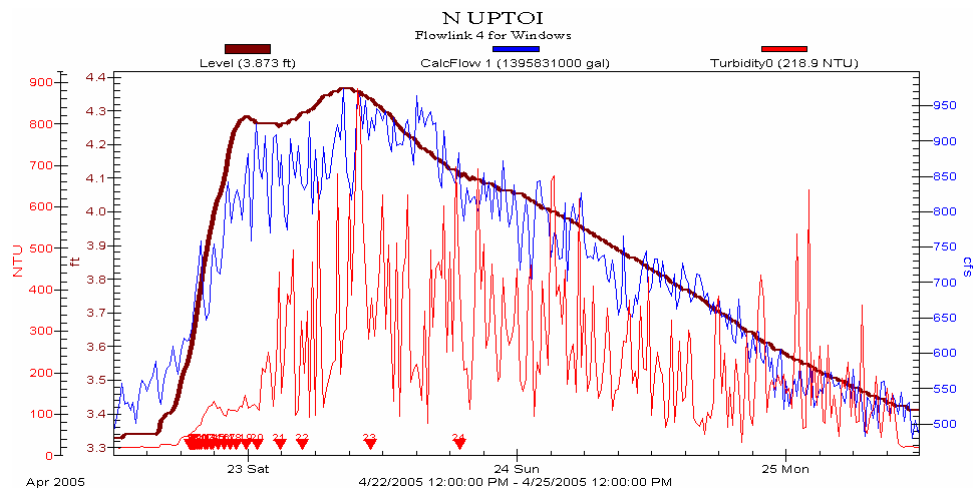


Figure 11-6. Storm of 22-25 April 2005 — the graph shows that turbidity values follow rise and fall pattern in stream level and flow velocity. Inverted triangles at the bottom are the times when respective samples were collected by Isco sampler.

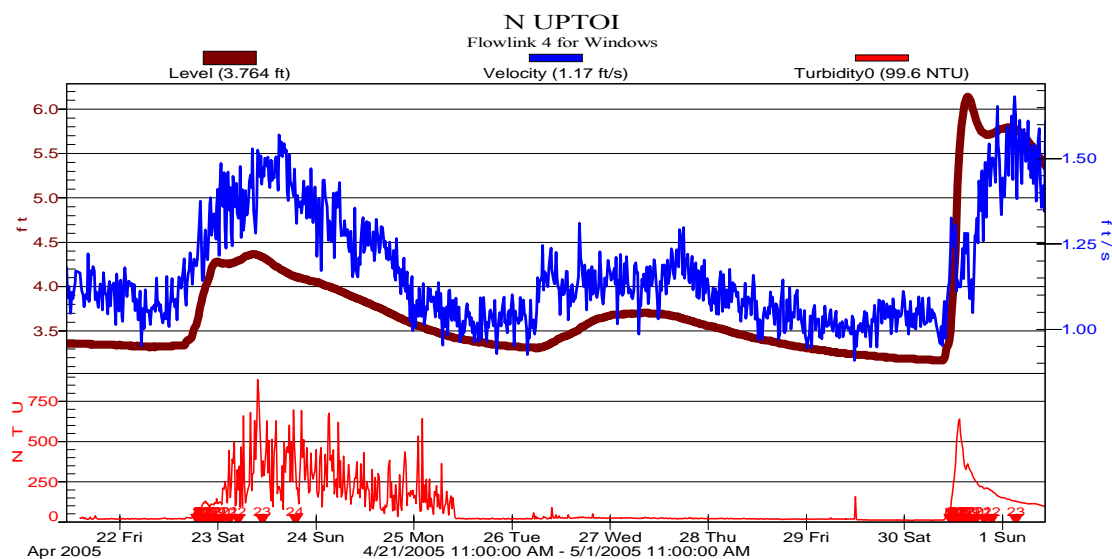


Figure 11-7. Two storm events between the period 21 April through 1 May 2005.

12 Host Site Coordinator Annual Report

At the conclusion of FY 2004, the SEMP Host Site Coordinator (HSC) has facilitated over 2500 field trips into the Fort Benning training area without a serious accident and without interfering with military training. In FY 2004, SEMP, SERDP, and associated other researchers conducted a record 750 field trips that required over 2500 training compartment reservations and 473 collocation agreements with military training units. The total number of field trips coordinated by SEMP increased in every year from FY2000-FY2004; however a reduction in field work is anticipated for FY2005. Figures 12-1, 12-2, and Tables 12-1 through 12-7 contain the data for the field trips.

This was the last full year of fieldwork for the original SEMP projects. ORNL 1 and SREL will conduct some minor fieldwork in FY2005, but this will take place before the start of the calendar year. All other SEMP fieldwork in FY2005 will be maintenance and monitoring conducted by the Ecosystem Characterization and Monitoring Initiative (ECMI). Prior to FY 2004, SEMP research accounted for most of the field crew-days at Fort Benning. In FY2004, 38 percent of the total field crew-days were attributable to SEMP, and in FY2005, only 14 percent of field crew-days are expected to be conducted by SEMP researchers.

A final tally of field work conducted by the original SEMP researchers is possible. The ECMI finished FY2004 with a total of 144 successful field trips. UFLG (CS1114a) conducted 504 field crew-days of research, Prescott (CS1114b) 186, ORNL1 (CS1114c) 187, ORNL2 (CS1114d) 16 and SREL (CS1114e) 717. At the completion of SEMP research, a total of 1,772 field crew-days were completed without any significant accidents or conflicts with the installation's training mission.

In FY 2004, additional SERDP-funded projects from SREL and ORNL accounted for about 26 percent of the total field effort. Pat Mullholland's ORNL3 (CS1186) riparian project commenced fieldwork in FY2001 and has completed most of the restoration phase of the project. The SREL Sandhill/TES Project (CS1302, Rebecca Sharitz, PI) commenced fieldwork in FY2003. This study uses remote sensing and modeling to identify xeric sandhill areas that would be expected to support rare plant and animal species. These additional SERDP-funded projects are expected to conduct about 44 percent of the field effort in FY2005.

Many other research groups use the services of the Host Site Coordinator to facilitate fieldwork at Fort Benning. The HSC schedules access to the training area, provides safety and UXO briefings, and provides technical advice based on an understanding of the installation ecology and culture. This coordination improves the research, promotes safety, and reduces the workload on installation trainers and managers. Many of these are small efforts — class field trips from Columbus State University for example.

Two projects in this category do conduct substantial field efforts at Fort Benning. The Army has funded several studies of the health effects of training and translocation on the gopher tortoise (*Gopherus polyphemus*). These studies require daily monitoring of live traps, and considerable coordination with installation activities. Another live trapping project is the Sparrow Winter Survivorship Study, an Army Legacy project conducted by the Institute for Bird Populations. This study requires daily access to bird banding stations and mist nets throughout the winter months. In FY2004, these other projects, that are not SERDP-funded, accounted for 36 percent of the total field effort coordinated by the HSC. In FY2005, this is expected to increase to 42 percent.

The Host Site Coordinator provides monthly reports on field research activity at Fort Benning and maintains an up-to-date GIS layer of all sample sites. These actions enable coordination of field studies between research projects and between the researchers and Fort Benning personnel.

In response to Force Protection requirements, Fort Benning made numerous changes in FY 2004 to the procedures used to control access to the installation. These changes placed new requirements on the researchers that were identified, explained, and facilitated by the HSC.

In FY2004, clearing commenced for a new Digital Multi Purpose Range Complex (DMPRC). This large project requires the clearing of over 1100 acres and substantial earth-moving activities. The DMPRC is located in the Bonham Creek and Sally Branch watersheds, which were the focus of much of the research conducted by SEMP. This project presents a unique opportunity to demonstrate the relevance of SEMP research, both in the utilization of data collected by SEMP and the actual application of monitoring techniques developed during the first 5 years of the project. Additionally, DMPRC provides a major disturbance which can be monitored to measure a wide suite of ecological consequences.

To take full advantage of this opportunity, and to support installation regulatory requirements, the HSC provided four briefings to SEMP cooperating researchers in FY2004. The HSC also organized a meeting between researchers and Fort Benning

environmental personnel to fully coordinate this effort. The results of these meetings were the adaptation of ongoing SEMP/SERDP research and the funding of additional monitoring efforts.

Fort Benning natural resources personnel have noted increased mortality of loblolly pines (*Pinus taeda*) throughout the installation. The issue of forest decline is of great importance to the recovery of the federally endangered red-cockaded woodpecker (*Picoides borealis*, RCW) and the implementation of forest management techniques designed to encourage development of the ecosystem of which the RCW is a cornerstone species. In FY 2004, the HSC participated in workshops on this topic and provided an interface between the installation and researchers to address this issue.

Another emerging issue at Fort Benning is the development of a plan for sustainable resource use. The Army Installation Management Agency sponsored a series of workshops to develop this plan in FY2004. The HSC attended these workshops and identified areas where ongoing or potential SEMP/SERDP research could assist in the long-range planning for mission changes and regional economic growth.

After 5 years of research activity at Fort Benning, SEMP has clearly demonstrated that ecological research can be safely conducted at a military installation without interfering with the national defense mission. SEMP research has greatly expanded the baseline knowledge of the ecology of Fort Benning and the southeastern Fall-Line/Sandhill ecoregion. SEMP has provided useful information to the installation in support of regulatory requirements and has made progress in addressing the issues of Ecosystems Management that are characteristic of multi-scale, multi-discipline, and multi-project research.

Table 12-1. Total field effort coordinated by SERDP at Fort Benning, 2000-2005.
Number of field crew-days FY2005 data is projected.

Project ID	FY2000	FY2001	FY2002	FY2003	FY2004	FY2005
ECMI (CS1114)	10	40	45	30	16	48
UFLG (CS1114a)	92	66	99	108	139	
Prescott (CS1114b)	49	49	47	38	3	
ORNL1 (CS1114c)	25	28	67	62	5	5
ORNL2 (CS1114d)	6	5	2	3		
SREL1 (CS1114e)	66	157	197	176	121	16
TOTAL SEMP	248	345	457	417	284	69
ORNL3 (CS1186)		25	44	94	167	142
SREL2 (CS1302)				52	31	76
TOTAL SERDP		25	44	146	198	218
GOPHER		120	1	127	152	90
IBP					116	116
TOTAL OTHER		120	1	127	268	206
TOTAL FIELDWORK	248	370	502	690	750	493

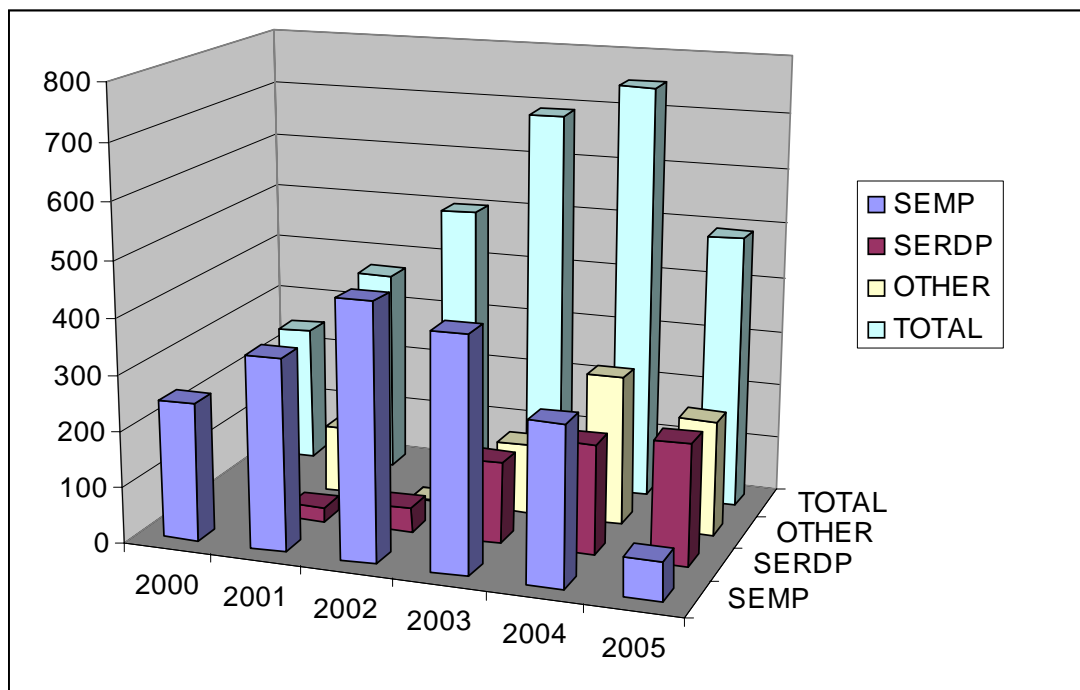


Figure 12-1. Total SERDP-coordinated field crew-days at Fort Benning (FY2000-FY2005).
FY2005 data is projected.

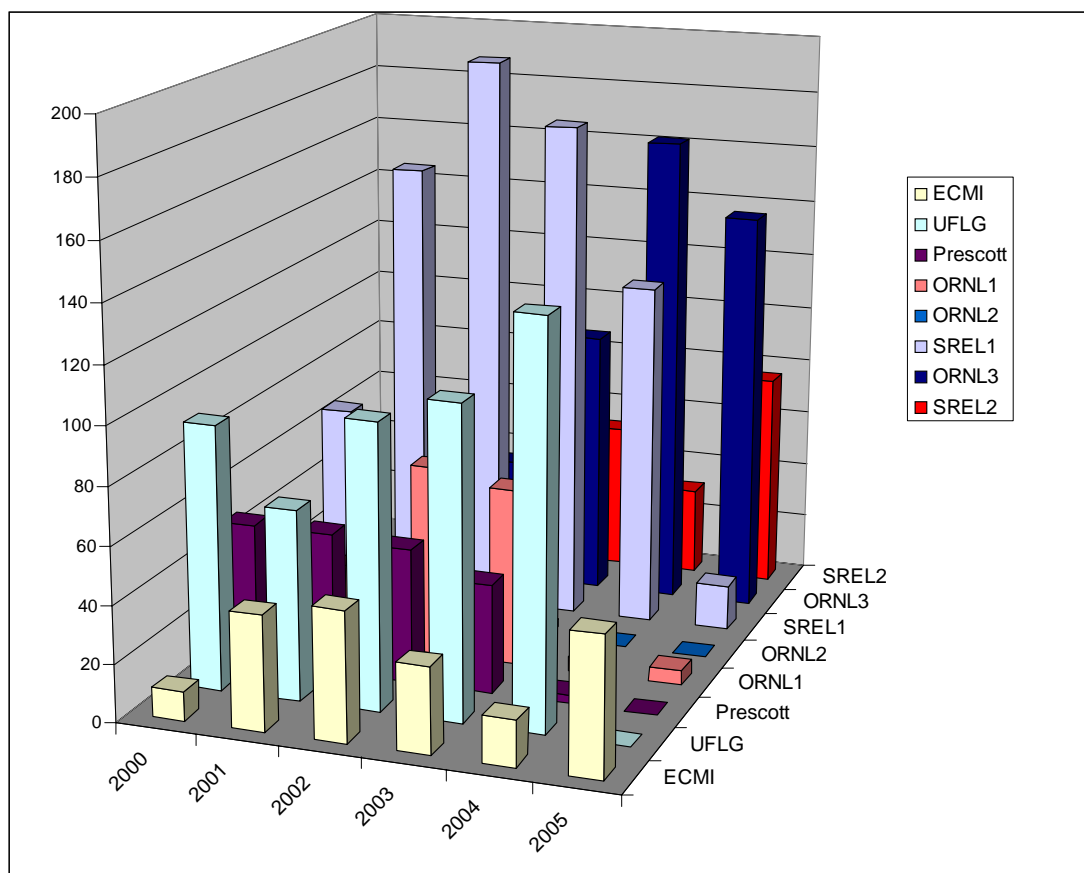


Figure 12-2. SERDP-funded field crew-days at Fort Benning (FY2000-FY2005) by project. FY2005 data is projected.

Table 12-2. Actual SEMP/SERDP field effort, FY 2000.

Number of field crew-days.

Month	ECMI CS1114	UFLG CS1114a	Prescott CS1114b	ORNL1 CS1114c	ORNL2 CS1114d	SREL CS1114e	ORNL3 CS1186	SREL2 CS1302	TOTAL
Oct				10					10
Nov									
Dec									
Jan	0	6	0	4					10
Feb	0	5	0	2	2				9
Mar	2	11	2	4	4				23
Apr	0	1	0	0	0	5			6
May	3	13	26	2	0	5			49
Jun	3	29	0	0	0	18			50
Jul	1	10	10	0	0	17			38
Aug	1	10	10	2	0	15			38
Sep	0	7	1	1	0	6			15
TOTAL	10	92	49	25	6	66			248

Note: Some fieldwork by ECMI and ORNL commenced in FY1999, but there are no records available.

Table 12-3. Actual SEMP/SERDP field effort, FY2001.

Number of field crew-days.

Month	ECMI CS1114	UFLG CS1114a	Prescott CS1114b	ORNL1 CS1114c	ORNL2 CS1114d	SREL CS1114e	ORNL3 CS1186	SREL2 CS1302	TOTAL
Oct	0	6	2	1	0	13			22
Nov	0	2	10	2	0	10			24
Dec	2	5	0	5	0	3			15
Jan	2	2	0	5	0	3			12
Feb	0	1	0	2	0	8			11
Mar	12	7	0	4	0	17	2		42
Apr	6	4	12	1	1	15	0		39
May	2	3	16	2	4	16	2		45
Jun	6	12	9	0	0	20	3		50
Jul	3	12	0	0	0	17	13		45
Aug	5	10	0	3	0	21	4		43
Sep	2	2	0	3	0	14	1		22
TOTAL	40	66	49	28	5	157	25		370

Table 12-4. Actual SEMP/SERDP field effort, FY 2002.

Number of field crew-days.

Month	ECMI CS1114	UFLG CS1114a	Prescott CS1114b	ORNL1 CS1114c	ORNL2 CS1114d	SREL CS1114e	ORNL3 CS1186	SREL2 CS1302	TOTAL
Oct	6	21	0	3	0	17	4		51
Nov	0	12	3	7	0	14	0		36
Dec	0	5	0	3	0	12	8		28
Jan	2	12	0	9	0	14	2		39
Feb	0	6	6	3	0	10	5		30
Mar	0	9	5	2	0	18	3		37
Apr	11	4	5	12	2	20	4		58
May	2	4	28	4	0	20	3		61
Jun	10	12	0	1	0	18	3		44
Jul	10	5	0	10	0	20	4		49
Aug	2	3	0	3	0	18	4		30
Sep	2	6	0	10	0	16	4		38
TOTAL	45	99	47	67	2	197	44		501

Table 12-5. Actual SEMP/SERDP field effort, FY 2003.

Number of field crew-days.

Month	ECMI CS1114	UFLG CS1114a	Prescott CS1114b	ORNL1 CS1114c	ORNL2 CS1114d	SREL CS1114e	ORNL3 CS1186	SREL2 CS1302	TOTAL
Oct	0	10	4	13	0	15	4	3	49
Nov	0	6	0	1	0	11	10	0	28
Dec	2	7	0	1	0	11	8	0	29
Jan	0	6	0	7	0	13	10	0	36
Feb	0	22	0	6	0	13	5	0	46
Mar	0	4	0	5	0	10	10	4	33
Apr	7	3	9	2	0	17	5	4	47
May	10	3	22	6	0	16	6	0	63
Jun	0	16	0	4	3	21	11	4	59
Jul	6	18	0	6	0	21	10	17	78
Aug	0	8	3	2	0	13	7	17	50
Sep	5	5	0	9	0	15	8	3	45
TOTAL	30	108	38	62	3	176	94	52	563

Table 12-6. Actual SEMP/SERDP field effort, FY 2004.

Number of field crew-days.

Month	ECMI CS1114	UFLG CS1114a	Prescott CS1114b	ORNL1 CS1114c	ORNL2 CS1114d	SREL CS1114e	ORNL3 CS1186	SREL2 CS1302	TOTAL
Oct	2	5	3	0	0	7	12	0	29
Nov	4	0	0	0	0	6	12	0	22
Dec	2	1	0	0	0	6	12	2	23
Jan	0	24	0	0	0	6	15	2	44
Feb	0	26	0	0	0	9	13	7	55
Mar	0	12	0	0	0	13	16	3	44
Apr	0	13	0	0	0	6	15	0	34
May	4	23	0	0	0	6	12	0	45
Jun	2	25	0	5	0	14	14	0	60
Jul	0	0	0	0	0	20	16	3	39
Aug	0	10	0	0	0	21	13	6	60
Sep	2	0	0	0	0	7	17	8	34
TOTAL	16	139	3	5	0	121	167	31	482

Table 12-7. Projected SEMP/SERDP field effort, FY 2005.

Month	ECMI CS1114	UFLG CS1114a	Prescott CS1114b	ORNL1 CS1114c	ORNL2 CS1114d	SREL CS1114e	ORNL3 CS1186	SREL2 CS1302	TOTAL
Oct	4			5		3	20	8	40
Nov	7					11	14	7	39
Dec	2					2	8	4	16
Jan	4						12	0	16
Feb	4						8	3	15
Mar	4						17	4	25
Apr	4						8	4	16
May	4						12	4	20
Jun	4						12	9	25
Jul	4						7	9	20
Aug	4						12	12	28
Sep	4						12	12	28
TOTAL	48			5		16	142	76	287

13 Summary

All the original SEMP research projects, whether from the Indicators area funded in FY1999 or the Thresholds area funded in FY2000, will have completed their funded work in CY 2004 or 2005. Some have handed in Final Reports during the period represented here, and the others will be due within a quarter following (i.e., by June 2005). The reports presented in this volume thus represent final or close-to-final content for these five projects. Summaries of all five final reports will appear in the 2005 SEMP report to close out the projects.

The SEMP project has undergone significant changes in its direction in the time period represented here. Both the SERDP Science Advisory Board (SAB) and the SEMP Technical Advisory Committee (TAC) expressed their desire to modify numerous aspects of the SEMP focus as well as its funding and administrative processes. While the FY04 Administrative Report (ERDC SR 06-1) approaches this in much greater depth for the use of its more restricted audience, many of the proposed changes are reflected in different sections of the this volume as well.

Another major structural change, which may have to wait to be observed here through comparisons between the present and proposed future content, is that new SEMP research projects will no longer be funded within the SEMP budget. They will be the results of responses to separate Statements of Need through the normal SERDP process, and will be coordinated with the SEMP project manager, but not controlled by him or her. The first of these “new” projects was included in the November 2004 announcements by SERDP as CS-SON 05-03, and was entitled “Developing Terrestrial Biogeochemical Cycle Models for Fort Benning Ecosystems.” The successful proposer, the USGS EROS Data Center, will be directly funded, and performs its own reporting and financial management processes outside the SEMP process. The SEMP project manager is, however, involved in supporting the USGS research team with respect to assistance in data acquisition and coordination with Fort Benning personnel and with the SEMP-supported staff on site at Fort Benning. It is anticipated that future SONs related to additional SEMP-related topics will be managed in this same manner.

Looking forward to 2005, significant change may be expected in almost every aspect of SEMP program management and execution. Some changes will be as a result of the SAB and TAC recommendations already referred to. Many more will be as an indirect result of those recommendations. At the request of the SAB, and after con-

sultation with the SEMP PM, the SERDP Program Office, and the SEMP TAC, a decision was made in late 2003 to contract with an external organization to conduct a comprehensive review of SEMP. The SERDP Program Office provided funds for this assessment, separate from the funds budgeted for SEMP. SERDP selected the RAND Corporation to conduct this review. RAND Corporation personnel conducted this assessment, and completed a draft report titled Assessment of the SERDP Ecosystem Management Project (SEMP) just before the September 9, 2004, SERDP SAB meeting, at which a summary of the results was presented. In summary, RAND recommended restructuring the SEMP project, using recommendations included in the assessment.

Copies of the report were provided, and a presentation was also given to Fort Benning staff and the SEMP TAC at their September 2004 meeting. The report provides a comprehensive assessment of the entire SEMP effort, and makes numerous recommendations for improvements in strategic planning, increasing relevance of SEMP to Fort Benning, improving program management, and improving the solicitation process for SEMP projects. The SEMP TAC and Fort Benning staff reviewed this report; their comments were included in the SEMP Presentation to the SERDP SAB on October 15th. The final version of this RAND report was completed in November 2004.

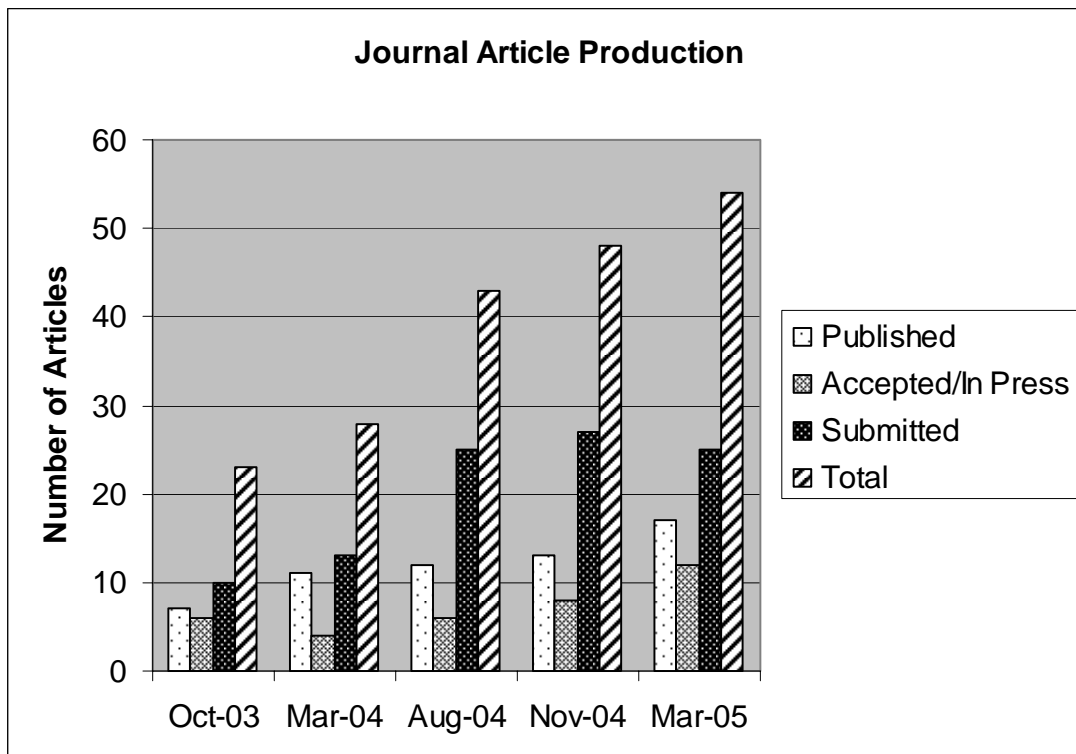
The SEMP Assessment has provided an excellent set of recommendations, most of which are being implemented in the SEMP restructuring strategy now being developed. Several of the recommendations were also immediately implemented, because they could be accomplished easily and within budget and time constraints. One of the key recommendations was to develop a new strategy for the second phase of SEMP; as noted below.

The greatest single changes of direction, which will be introduced more fully in 2005, represent the response to SAB, TAC, and RAND suggestions that the SEMP focus be more directly on needs of Fort Benning land managers. In a sense, this represents an almost total reversal of philosophy. One might have referred to the original SEMP focus as being one of studying the ecosystem characteristics, following the guidance from the organizing workshop, with the hope that the principles discovered would prove of value in land management on any military installation. The new process would be to identify land management needs, and design research and studies to assist the installation in problem solutions that would have immediate application within existing processes. A workshop was held among Fort Benning land management personnel in January 2005 to identify such needs, and was followed by a SEMP workshop in February, 2005, where a mix of Fort Benning staff, SEMP researchers, TAC members, and several outside experts reviewed these results. The follow-on recommendations focused on two areas of need, forest health

and water quality management. It is expected that future SONs and study proposals will focus on these mutually-agreed topic areas.

Appendix A: SEMP Publications (as of April 2005)

Journal Articles					
	Oct-03	Mar-04	Aug-04	Nov-04	Mar-05
Published	7	11	12	13	17
Accepted/In Press	6	4	6	8	12
Submitted	10	13	25	27	25
TOTAL	23	28	43	48	54



Summary of Publications

APRIL 2005:

Journal Articles	
Published:	17
Accepted/In Press:	13
Submitted:	22

Books and Book Chapters: 1

Technical Reports	
Published:	21
In Press:	0
Submitted:	3

Theses and Dissertations: 10

CS 1114A – University of Florida and Purdue University – Dr. Reddy

Journal Articles

Accepted/In Press

Bhat, S., J.M. Jacobs, K. Hatfield, and J. Prenger. Ecological indicators in forested watersheds in Fort Benning, GA: relationship between land use and stream water quality. *Ecological Indicators*. (In press)

Bryant, M.L., S. Bhat, and J.M. Jacobs. Spatiotemporal throughfall characterization of heterogeneous forest communities in the southeastern U.S. *Journal of Hydrology*. (In press)

Submitted

Archer, J., and D.L. Miller. Understory vegetation and soil response to silvicultural activity in a southeastern mixed pine forest: a chronosequence study. *Journal of Forest Ecology and Management*. (Submitted January 2004)

Bhat, S., K. Hatfield, J.M. Jacobs, R. Lowrance, and R. Williams. Prediction of Nitrogen Leaching from Freshly Fallen Leaves: Application of Riparian Ecosystem Management Model (REMM). *Forest Ecology and Management*. (Submitted January 2005)

Bhat, S., J.M. Jacobs, K. Hatfield, and W. Graham. Hydrological Indicators of Watershed Scale Military Impacts in Fort Benning, GA. *Journal of Hydrology*. (Submitted September 2004)

Cohen, M.J., S. Dabral, W.D. Graham, J.P. Prenger, and W.F. DeBusk. Evaluating ecological condition using soil biogeochemical parameters and near infrared reflectance spectra. *Environmental Modeling and Assessment*. (Submitted December 2004)

DeBusk, W. F., B.L. Skulnick, J.P. Prenger, and K. R. Reddy. Response of soil organic carbon dynamics to disturbance from military training. *Soil and Water Conservation*. (Submitted November 2004)

Dabral, S., W.D. Graham, and J.P. Prenger. Quantitative analysis of soil nutrient concentrations with near infrared spectroscopy and partial least squares regression. *Soil Science Society of America Journal*. (Submitted March 2004)

Ogram, A, Hector Castro, E. A. Stanley, Chen, Weiwei, and J. P. Prenger. Distribution of methanotrophs in managed and highly degraded watersheds. *Ecological Indicators*. (Submitted June 2004)

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CS 1114B – Prescott College – Dr. Krzysik

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CS 1114D – ORNL – Mr. Garten**Journal Articles****Published**

Garten, C.T., Jr., T.L. Ashwood, and V.H. Dale. 2003. Effect of military training on indicators of soil quality at Fort Benning, Georgia. *Ecological Indicators* 3:171-179.

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Monitoring Research Program – ERDC/EL – Dr. Price**Journal Articles****Published**

Jackson, S. and Bourne, S. 2005. Using Feature Extraction to Monitor Urban Encroachment, *Earth Observation Magazine*, Vol. 14, No. 2, pp. 26-29.

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Bourne, S.G., and M.R. Graves. 2001. Classification of land-cover types for the Fort Benning ecoregion using Enhanced Thematic Mapper data. ERDC/EL TN-ECMI-01-01. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

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Graves, M.R., and S.G. Bourne. 2002. Landscape pattern metrics at Fort Benning, Georgia. ERDC/EL TN-ECMI-02-2. U.S. Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS.

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Balbach, H.E., W.D. Goran, T. Aden, D.L. Price, M.R. Kress, W.F. DeBusk, A.J. Krzysik, V.H. Dale, C. Garten, Jr., and B. Collins. 2002. Strategic Environmental Research and Development Program (SERDP) Ecosystem Management Project (SEMP) FY01 annual report. ERDC SR-02-2. U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, IL.

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Lozar, R.C., H.E. Balbach, W.D. Goran, and B. Collins. 2002. Proceedings of the "Partners Along The Fall Line: Sandhills Ecology and Ecosystem Management Workshop." ERDC/CERL SR-02-2. U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory, Champaign, IL.

Appendix B: SEMP Documents

	1999	2000	2001	2002	2003	2004	2005	Total:
Monthly HSC Report	0	0	9	12	12	12	1	46
Fact Sheets	0	0	7	8	0	8	1	24
TTAWG TAC IPR SAB Briefings	5	5	14	19	21	15	7	86
Annual Reports	0	6	14	11	8	1	0	40
Technical Reports	0	1	7	9	0	10	0	27
Project Summary	0	0	1	0	12	16	7	36
Quarterly Report	0	15	27	22	23	18	0	105
Management Plans	0	3	12	12	10	20	5	62
Theses and Dissertations	0	1	2	3	2	2	0	10
Professional Society Presentations	1	3	4	10	24	8	3	53
Journal Articles	0	0	2	4	3	5	3	17
Total:	6	34	99	110	115	115	27	506

